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ABSTRACT

This report is the documentation of a FORTRAN program that calculates the atmospheric cooling rate and infrared fluxes for partly cloudy atmospheres based upon the fast but accurate methods of Chou and Arking (1978, 1980). The IR fluxes in the water bands and the 9.6 and 15 μm bands are calculated at 15 levels ranging from 1.39mb to the surface.

The program is generalized to accept any arbitrary atmospheric temperature and humidity profiles and clouds as input and return the cooling rate and fluxes as output. Sample calculations for various atmospheric profiles and cloud situations are demonstrated in the report.

A digital magnetic tape containing the computer codes and the precomputed transmission functions of the radiation routine can be made available upon request.

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1. INTRODUCTION

Radiative heating and cooling play a crucial role on our climate system. The need for a fast yet accurate radiation routine has become more and more demanding as large-scale numerical models are now commonly used as a powerful tool to understand atmospheric processes and to study climatic problems. It has been a fact that the calculation of the radiative terms takes a large percentage, sometimes up to 90%, of the computing time spent in a numerical experiment. Usually, the percentage increases with the accuracy of a radiation routine that leads to the painful choice of a crude radiation routine in long-term climate studies.

Fast yet accurate radiation routines which include both water vapor and carbon dioxide bands have recently been developed by Chou and Arking (1978,¹ 1980²). These routines for clear atmospheres are extended to include partly cloudy situations under the assumption that clouds are either black or gray. The computer codes of the radiation routine are described in detail in this report. Radiative transfer equations for fluxes are first presented in Section 2, simplifications of the transmission functions are then given in Section 3. Section 4 depicts the model structure and the approach to the vertical integration of the transfer equations. Section 5 describes the computer codings of the radiation routine. The computer program is listed in Appendix A with arrays and variables tabulated in Appendix B. Some sample calculations are demonstrated in Appendix C.

2. RADIATIVE TRANSFER EQUATIONS

In this radiation routine, the infrared spectrum is divided into four regions: the $15\mu\text{m}$ CO_2 band, the $9.6\mu\text{m}$ O_3 band, the water vapor band center region and the band wing region. Clouds

¹Chou, M. D. and A. Arking, 1978. An infrared radiation routine for use in numerical atmospheric models. Preprint, Third Conference on Atmospheric Radiation, American Meteorological Society, 303-305.

²Chou, M. D. and A. Arking, 1980: Computation of infrared cooling rates in the water vapor bands. J. Atmospheric Sciences, 37, 855-867.

are treated as either black or gray, and scattering due to molecules and particulates is neglected. Fluxes in each spectral region are computed for clear and cloudy atmospheres. These fluxes are then weighted by the fraction of sky cover to obtain the total flux.

For a clear atmosphere, the upward and downward fluxes at pressure level p integrated over the spectral range $\Delta\nu$ can be computed respectively from

$$F_{\text{clr}} \uparrow (p) = \int_{\Delta\nu} d\nu \left[B_\nu(T_s) \tau_\nu(p, p_s) + \int_{p_s}^p B_\nu(T(p')) \frac{d\tau_\nu(p, p')}{dp'} dp' \right] \quad (1a)$$

and

$$F_{\text{clr}} \downarrow (p) = \int_{\Delta\nu} d\nu \left[\int_{p_t}^p B_\nu(T(p')) \frac{d\tau_\nu(p', p)}{dp'} dp' \right] \quad (1b)$$

where $B_\nu(T)$ is the blackbody flux at temperature T and wavenumber ν and is equal to π times the Planck radiance, $\tau_\nu(p, p')$ the diffuse transmittance between the levels p and p' , and the subscripts s and t denote the surface and the top of the atmosphere, respectively.

Because of the rapid variation of transmittance with wavenumber, the use of Eqs. (1a) and (1b) to compute fluxes is a very time-consuming process. Simplifications of Eqs. (1a) and (1b) are applied to different spectral bands. In the 9.6 and 15 μm bands, the transmittance τ_ν is replaced by its average value over $\Delta\nu$ which reduces the equations for fluxes to

$$F_{\text{clr}} \uparrow (p) = B(T_s) \tau(p, p_s) + \int_{p_s}^p B(T(p')) \frac{d\tau(p, p')}{dp'} dp' \quad (2a)$$

and

$$F_{\text{clr}} \downarrow (p) = \int_{p_t}^p B(T(p')) \frac{d\tau(p, p')}{dp'} dp', \quad (2b)$$

where

$$B(T) = \int_{\Delta\nu} B_\nu(T) d\nu. \quad (2c)$$

and

$$\tau(p, p') = \frac{1}{\Delta\nu} \int_{\Delta\nu} \tau_\nu(p, p') d\nu. \quad (2d)$$

In the water vapor bands, the flux computations are simplified by integrating Eqs. (1a) and (1b) by parts and reducing them to

$$F_{\text{clr}} \uparrow (p) = B(T(p)) + G(p, p_s, T_s) - G(p, p_s, T(p_s)) + \int_{T(p)}^{T(p_s)} \partial G(p, p', T(p')) / \partial T dT(p'), \quad (3a)$$

and

$$F_{\text{clr}} \downarrow (p) = B(T(p)) - G(p, p_t, T(p_t)) + \int_{T(p)}^{T(p_t)} \partial G(p, p', T(p')) / \partial T dT(p'), \quad (3b)$$

where

$$G(p, p', T) = \int_{\Delta\nu} \tau_\nu(p, p') B_\nu(T) d\nu. \quad (3c)$$

and

$$\partial G(p, p', T) / \partial T = \int_{\Delta\nu} \tau_\nu(p, p') \partial B_\nu(T) / \partial T d\nu. \quad (3d)$$

It is noticed that the Planck function varies significantly within a wide spectral interval. The use of Eqs. (2a) and (2b) to compute fluxes would introduce significant errors unless the water vapor bands are divided into a number of intervals ($\gtrsim 10$). With the G-function computed from Eq. (3c) using the line-by-line method, the effect of the variation of Planck function with wave-number is correctly taken into account. The reason that Eqs. (3a) and (3b) are applied only to the water vapor bands is that we have not yet developed methods for precomputing the G-function in the CO₂ and O₃ bands. This will become clear in Section 3.

For a cloudy atmosphere, Eq. (2a) is used to compute fluxes in the 9.6 and 15 μm bands except that the subscript s is replaced by CT for upward fluxes and CB for downward fluxes, where CT denotes the cloud top and CB the cloud base. Similarly, Eq. (3a) is used to compute fluxes in the water vapor bands with the subscript s replaced by CT and CB respectively for upward and downward fluxes.

For a partly cloudy atmosphere, the infrared flux is computed from

$$F(p) = (1 - C)F_{\text{clr}}(p) + \sum_{i=1}^n C_i F_i^{\text{cld}}(p), \quad (4)$$

where F^{cld} is the flux for a cloudy atmosphere, C the total fractional cloud cover, C_i the cloud cover of type i , and n the number of cloud types. The cooling rate is proportional to the flux divergence given by

$$- \frac{dT}{dt} = \frac{g}{C_p} \frac{d}{dp} (F_{\downarrow} - F_{\uparrow}), \quad (5)$$

where C_p is the heat capacity of air and g the acceleration of gravity.

3. COMPUTATION OF TRANSMISSION FUNCTIONS

The most difficult part in computing radiative fluxes in the atmosphere is the integration over the entire spectrum. Usually the absorption coefficient changes several orders of magnitude within a spectral interval of 100 cm^{-1} , and the transmittance τ_{ν} in Eq. (1) must be computed at every $\lesssim 0.01 \text{ cm}^{-1}$ interval, which results in a total of 10^5 – 10^6 points along the spectrum. Since we are interested in the total flux but not the flux at individual wavenumber, the point-by-point calculation is commonly replaced by wide band (or emissivity) or narrow band approximations. In this section, we describe the method used in our radiation routine to eliminate the difficulty in computing transmission functions in various parts of the spectrum.

a. Basic Equations

The beam transmittance between any two pressure levels p_1 and p_2 at wavenumber ν in the direction from the vertical $\theta = \cos^{-1}\mu$ is

$$\tau_{\nu}(\mu) = \exp \left(- \sum_i u_{\nu}(i)/\mu \right) \quad (6)$$

where $u_{\nu}(i)$ is the optical depth of the i th absorber given by

$$u_{\nu}(i) = \frac{1}{g} \int_{p_1}^{p_2} k_{\nu}(i) q(i) dp, \quad (7)$$

k_{ν} , the absorption coefficient and q the mixing ratio.

The diffuse transmittance in Eqs. (1) and (3c) is related to the beam transmittance by

$$\tau_{\nu} = 2 \int_0^1 \tau_{\nu}(\mu) \mu d\mu, \quad (8)$$

b. Absorption Coefficients

The absorbers considered in this radiation routine include water vapor, carbon dioxide, and ozone. The parameters needed for computing the molecular line absorption are the position, ν_0 , strength, S , width, α , and shape of molecular lines. Using the parameters compiled by McClatchey et al. (1973³) and assuming a Voigt line function, the absorption coefficients are computed using the line-by-line method at every 0.01 cm⁻¹ interval for individual absorbers.

The e-type continuum absorption due to water vapor in the spectral region between 340 and 1200 cm⁻¹ is also included. The regression curve given in Roberts et al. (1976⁴) which fits laboratory data is used to compute the absorption coefficient at 296 K.

c. Scaling Approximation for Water Vapor Absorption

In the water vapor bands, the efficiency of the flux computation can be further increased by taking advantage of the nature of water vapor distribution. Generally the water vapor decreases logarithmically with height. The lower troposphere is too opaque to have significant cooling for the spectral intervals near the center of the absorption bands, whereas the upper troposphere is too transparent to have significant cooling for the band wings. As shown in Chou and Arking (1980) that the cooling rate has a relatively narrow vertical profile that peaks at the upper

³McClatchey, R. A., W. S. Benedict, S. A. Clough, D. E. Burch, R. F. Calfee, K. Fox, L. S. Rothman and J. S. Garing, 1973: AFCRL atmospheric absorption line parameters compilation. Environ. Res. Pap., No. 434, AFCRL-TR-73-0096.

⁴Roberts, R. E., J. E. A. Selby, and L. M. Biberman, 1976: Infrared continuum absorption by atmospheric water vapor in the 8-12 μ m window. Applied Optics, 15, 2085-2090.

troposphere for the band center region and at the lower troposphere for the band wing region. By scaling the absorption coefficient (or alternatively the water vapor amount) separately for the band center region and the band wing region based on the temperature and pressure at the height where the cooling rate is a maximum, the difficulty in computing the absorption coefficient for various temperature and pressure can be greatly reduced.

At the levels where cooling is significant, absorption quickly saturates near the center of most of the molecular lines, and the cooling rate is mainly due to the region in line wings. In the far wings, where $|\nu - \nu_0| \gg \alpha$, the water vapor molecular line absorption, ℓ_ν , can be written as

$$\ell_\nu(p, T) = \ell_\nu(p_r, T_r) \frac{p}{p_r} R(T, T_r) \quad (9)$$

where R is the spectrally averaged value of R_ν given by

$$R_\nu(T, T_r) = \left(\frac{T_r}{T} \right)^{1/2} \frac{\sum_i \left[\frac{S_i(T) \alpha_i(p_r, T_r)}{(\nu - \nu_{oi})^2} \right]}{\sum_i \left[\frac{S_i(T_r) \alpha_i(p_r, T_r)}{(\nu - \nu_{oi})^2} \right]} \quad (10)$$

and the index i denotes absorption lines.

In Eq. (9), the absorption coefficient at the reference conditions, $\ell_\nu(p_r, T_r)$, is "exactly" computed using line-by-line method. The error in $\ell_\nu(p, T)$ using the far-wing scaling approximation depends upon the departure of p and T from p_r and T_r . Since the water vapor cooling profile spans only a narrow region in the vertical, the error in cooling rate arising from the use of Eq. (9) is minimal if we choose the reference temperature and pressure to be in the region of maximum cooling. Table 1 shows the spectral regions, the reference temperature and pressure, and the mean values of R_ν for the band center region and the band wing region. The reference temperature and pressure are chosen to correspond to conditions at the level of maximum cooling rate in the U.S. Standard Atmosphere. In Table 1, the temperature scaling term R is given only at two temperatures. Values of R at other temperatures are computed using a quadratic fit to the R -values at $T = T_r \pm 40K$ and $T = T_r$ (for which $R = 1$).

Table 1

The reference temperature T_r and pressure p_r , are specified for the center and the wing regions of the water vapor absorption bands. The effect of temperature on the absorption coefficient is indicated by $R(T, T_r)$, which is the mean value of the function $R_p(T, T_r)$ defined by Eq. (10).

	Wavenumber (cm^{-1})	$T_r(\text{K})$	$p_r(\text{mb})$	$R(T_r - 40, T_r)$	$R(T_r + 40, T_r)$
Center	0-340	225	275	0.90	1.16
	1380-1900				
Wing	340-580	256	550	0.58	1.78
	760-980				
	1100-1380				
	1900-3000				

d. Diffuse Transmittance in the $15\mu\text{m}$ Band

The absorption in the $15\mu\text{m}$ band from 580 to 760cm^{-1} is due primarily to CO_2 and secondarily to water vapor. The overlapping of diffuse transmittances is approximated by

$$\tau_{15\mu} = \tau_{\text{CO}_2} \cdot \tau_l \cdot \tau_e, \quad (11)$$

where τ_{CO_2} , τ_l , and τ_e are the transmittances averaged over the $15\mu\text{m}$ band due to CO_2 molecular line absorption, H_2O line absorption and H_2O e-type absorption, respectively.

The atmospheric CO_2 content can practically be considered as constant, and the transmittance τ_{CO_2} between any pressure levels is a function of temperature only. Since the relative change in atmospheric temperature is not large, Arking (1976⁵) used a linear expansion method to correct for small variation in the beam transmittance for temperature retrievals. This method introduces an error ≤ 0.005 in the mean diffuse transmittance averaged over the entire $15\mu\text{m}$ band (Chou and Arking, 1978). In this infrared radiation routine, the transmittance τ_{CO_2} between p_1 and p_2 is computed using the linear expansion method from

$$\tau_{\text{CO}_2}(p_1, p_2) = \tau_{\text{CO}_2}^{\circ}(p_1, p_2) + \sum_{i=1}^m a_i(p_1, p_2) \Delta T_i, \quad (12)$$

⁵Arking, A., 1976: The proper weighting function for deriving temperatures from satellite measured radiances. GSFC X-document X-911-76-48.

where the superscript o denotes the transmittance for a reference temperature profile, m the layers between p_1 and p_2 , and ΔT the deviation of temperature from the reference temperature. The coefficient a_i is given by

$$a_i(p_1, p_2) = \partial \tau(p_1, p_2) / \partial T_i. \quad (13)$$

The e-type continuum absorption coefficient, C_v , increases with vapor pressure but decreases with temperature according to (see Roberts et al., 1976)

$$C_v(T) = C_v(T_0) e \cdot \exp \left[- \frac{1800}{T_0} + \frac{1800}{T} \right], \quad (14)$$

where $C_v(T_0)$ is the absorption coefficient at $p = 1$ atm and $T = T_0$, and e the vapor pressure in atms.

With the use of Eq. (14) and the far-wing scaling approximation, Eq. (9), the transmittances τ_Q and τ_e are computed from

$$\tau_Q(w) = \frac{2}{\Delta \nu} \int_{\Delta \nu} d\nu \int_0^1 \exp(-\ell_\nu(p_r, T_r) w / \mu) \mu d\mu, \quad (15)$$

$$\tau_e(u) = \frac{2}{\Delta \nu} \int_{\Delta \nu} d\nu \int_0^1 \exp(-C_v(T_0) u / \mu) \mu d\mu, \quad (16)$$

where the scaled water vapor amounts are given by

$$w(p_1, p_2) = \frac{1}{g} \int_{p_1}^{p_2} \left(\frac{p}{p_r} \right) R(T, T_r) q dp, \quad (17)$$

$$u(p_1, p_2) = \frac{1}{g} \int_{p_1}^{p_2} e \cdot \exp \left(- \frac{1800}{T_0} + \frac{1800}{T} \right) q dp. \quad (18)$$

Values of $\tau_{CO_2}^o(p_1, p_2)$, $a_i(p_1, p_2)$, $\tau_Q(w)$, and $\tau_e(u)$ are precomputed using the line-by-line method and stored in tables for later use. The reference conditions are chosen to be the same as the water vapor band wing region, i.e., $p_r = 550$ mb and $T_r = 256$ K. Values of R are approximated by that given in Table 1 for the band wing region.

e. Diffuse Transmittance in the 9.6 μ m Band

In the 9.6 μ m band from 980 to 1100cm⁻¹, the absorption is mostly due to ozone in the stratosphere. The water vapor e-type absorption contributes somewhat to the cooling in the lower tropical atmosphere, but the effect of line absorption is negligible. Applying the multiplication approximation, the diffuse transmittance is computed from

$$\tau_{9.6\mu} = \tau_{O_3} \cdot \tau_e. \quad (19)$$

The ozone transmittance, τ_{O_3} , is precomputed using the line-by-line method for the three latitude zones, 0-30, 30-60, 60-90°N. Annual mean ozone content and temperature profile at 15, 45, and 75°N are used to compute τ_{O_3} for the respective latitude zones. No attempts have been made to correct for the change in τ_{O_3} due to changes in the ozone content and temperature profile. The transmittance τ_e is precomputed from Eq. (16) and stored in a table as a function of the scaled water vapor amount, u .

f. The G-Function for the Water Vapor Bands

Utilizing the far-wing scaling approximation, the water vapor transmittance between p_1 and p_2 can be written as

$$\tau_\nu(p_1, p_2) = 2 \int_0^1 \exp - [(\ell_\nu(p_r, T_r) w(p_1, p_2) + C_\nu(T_0) u(p_1, p_2))/\mu] \mu d\mu; \quad (20)$$

where $w(p_1, p_2)$ and $u(p_1, p_2)$ are given by Eqs. (17) and (18). The error introduced in $\tau_\nu(p_1, p_2)$ by using Eq. (20) was shown in Chou and Arking (1980) to be small with a magnitude $\lesssim 0.01$.

Since $\ell_\nu(p_r, T_r)$ and $C_\nu(T_0)$ are functions of wavenumbers only, the G-function defined in Eq. (3c) depends on w , u , and T , but not on the detailed temperature and humidity profiles. The function $G(p, p', T)$ in Eqs. (3a) and (3b) can then be approximated by $G(w, u, T)$ with w and u being the scaled water vapor amounts in the column between p and p' . It is now possible to precompute the three-dimensional function of $G(w, u, T)$ using the line-by-line method and the results stored in tables. The G-function defined in Eq. (3c) is computed for the band wing

region and the band center region with spectral interval $\Delta\nu$ listed in Table 1. A table look-up for the G-function makes the computations of fluxes very fast from Eqs. (3a) and (3b).

4. VERTICAL INTEGRATION FOR FLUXES

a. Model Structure

Since the functions B, τ , and G in Eqs. (2) and (3) are highly non-linear with respect to height, the vertical integrations cannot be performed analytically. The continuous atmosphere is therefore discretized by dividing it into a number of layers, and the integrations approximated by summations. The fluxes are computed at 15 levels (designated as flux levels hereafter) separated by $\Delta \ln p = 0.828$ above the 200mb level and $\Delta p = 100$ mb below. Since the layers are too thick (in terms of the differences in the Planck and transmission functions at the boundaries) for flux computations, each layer is further divided into 3 sublayers with equal $\Delta \ln p$ above the 200 mb level and equal Δp below. Thus, there are 43 sublevels and 42 sublayers in the vertical. Fig. 1 illustrates the pressure at these levels.

b. Temperature and Humidity Interpolations

Given temperature and humidity at any pressure levels as inputs to the radiation routine, they are interpolated (or extrapolated) to the 43 sublevels and the middle of each of the 42 sublayers. Temperature and the logarithm of specific humidity are interpolated linearly in $\ln p$.

c. Vertical Integrations

Let j be the index for sublevels increasing downward and $j + \frac{1}{2}$ for the sublayer immediately below, then the following approximations are made in computing fluxes at the level p_i in the 9.6 and $15\mu\text{m}$ bands (see Fig. 1 for the locations of i and j),

$$B(T(p')) d\tau(p_i, p') \simeq B(T_{j+\frac{1}{2}}) [\tau(p_i, p_{j-1}) - \tau(p_i, p_j)], j = i + 1, \dots, 43, \text{ for upward flux;} \quad (21a)$$

$$\simeq B(T_{j+\frac{1}{2}}) [\tau(p_i, p_{j+1}) - \tau(p_i, p_j)], j = 1, \dots, i - 1, \text{ for downward flux.} \quad (21b)$$

Similarly, the following approximations are made in computing water vapor infrared fluxes,

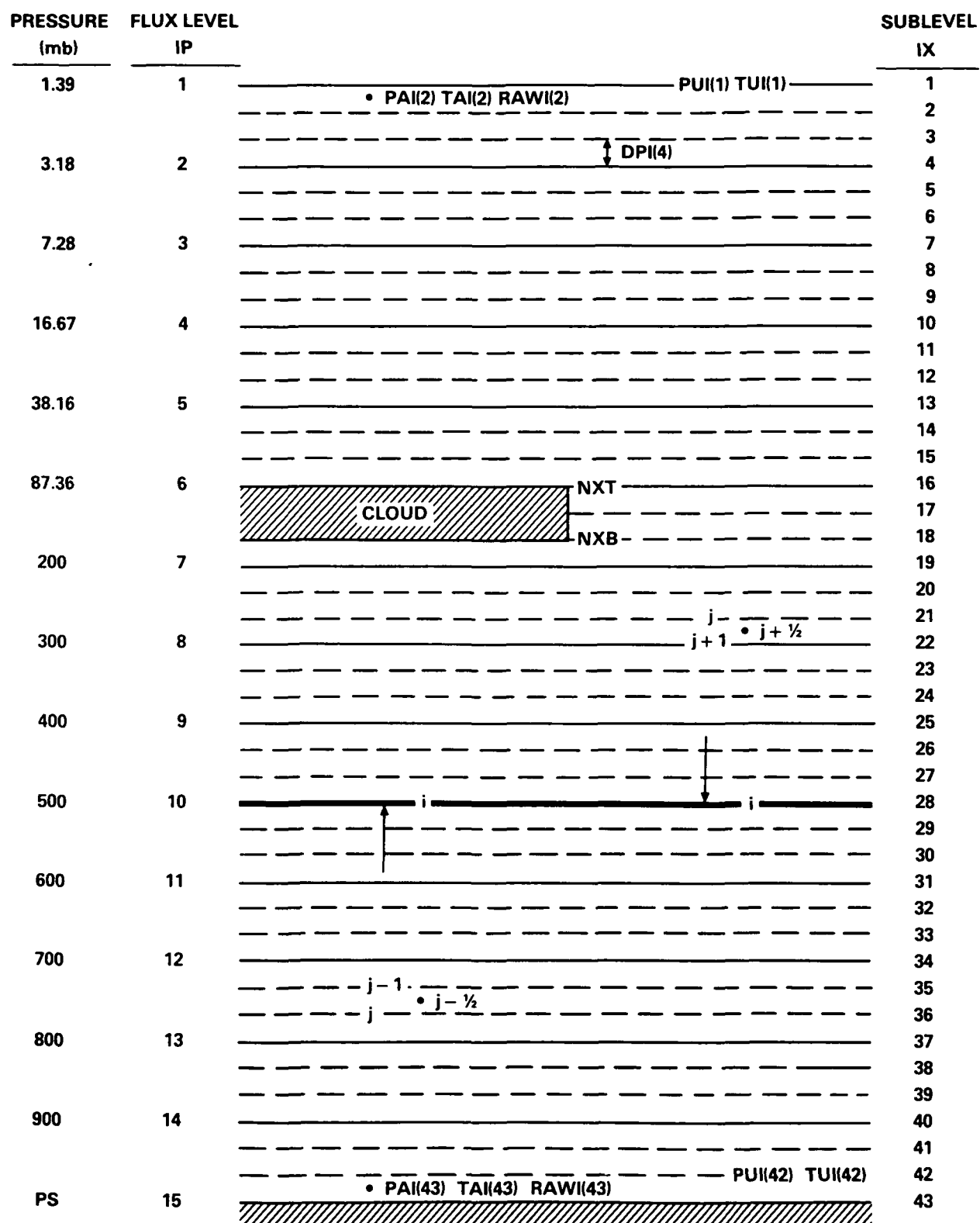


Figure 1. Model Vertical Structure. Sublevels are Used for Computing Fluxes at the Flux Levels.

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$$\begin{aligned}
 & [\partial G(p_i, p', T(p')) / \partial T(p')] dT(p') \\
 & \simeq G(w(p_i, p_{j-1/2}), u(p_i, p_{j-1/2}), T_j) \\
 & \quad - G(w(p_i, p_{j-1/2}), u(p_i, p_{j-1/2}), T_{j-1}), j = i + 1, \dots, 43, \\
 & \quad \text{for upward flux;} \tag{22a}
 \end{aligned}$$

$$\begin{aligned}
 & \simeq G(w(p_{j+1/2}, p_i), u(p_{j+1/2}, p_i), T_j) \\
 & \quad - G(w(p_{j+1/2}, p_i), u(p_{j+1/2}, p_i), T_{j+1}), j = 1, \dots, i - 1, \\
 & \quad \text{for downward flux.} \tag{22b}
 \end{aligned}$$

5. INFRARED RADIATION CODE

The program is divided into 6 sections. The main routine is for specifying the input data and for returning the fluxes and the cooling rate. The fixed data that accompany the program are read in the subroutine INDATA. The third routine GAMOTO interpolates the input data of cloud heights, temperature, and humidity to the model levels and computes the scaled water vapor amounts for each layer. The subroutine IRH2O interpolates the G-function in the water vapor bands which is used in the subroutine FDIVER to compute fluxes in the water vapor bands. Finally, the subroutine RCO2O3 computes the fluxes in the 9.6 and 15 μ m bands. Subroutines IRH2O and RCO2O3 are independent of each other. In the following, variables and arrays in the routines are all denoted by capital letters.

a. Main Program

The main program is to accept the input data and return the computed fluxes and cooling rate.

The users must specify the following input data

<u>Input Data</u>	<u>Unit</u>	<u>Code</u>
Pressure	mb	PA
Temperature	K	TA
Humidity	gm/gm	WA
Surface temperature	K	TS
Surface pressure	mb	PS

<u>Input Data</u>	<u>Unit</u>	<u>Code</u>
Cloud top pressure	mb	CLTOP
Cloud base pressure	mb	CLBOT
Fractional cloud amount		CSS
Number of pressure levels		NDATA
Number of cloud types		NC
Latitude	degree	RLAT

The user's input of pressure, temperature and humidity define the atmospheric profiles. These data must be arranged in order of increasing pressure. The surface pressure, PS, must be greater than 900mb. Different cloud types are treated as non-overlapping. For cloud-free atmospheres, the parameter NC is set to zero.

The following parameters are the outputs of the infrared radiation routine:

<u>Parameter</u>	<u>Unit</u>	<u>Code</u>
Downward flux in the water vapor bands	ergs/(cm ² sec)	FLUXHD
Upward flux in the water vapor bands	ergs/(cm ² sec)	FLUXHU
Downward flux in the 9.6 and 15μm bands	ergs/(cm ² sec)	FLUXCD
Upward flux in the 9.6 and 15μm bands	ergs/(cm ² sec)	FLUXCU
Cooling rate	°C/day	COOLR

Fluxes are computed at the 15 levels denoted by the running variable IP in Fig. 1, and cooling rates are computed for the layers defined by the flux levels. The spectral ranges for water vapor bands are listed in Table 1. The cooling rate is computed from Eq. (5) with $C_p = 1.003 \times 10^7$ ergs/(gm K).

b. Subroutine INDATA

This subroutine reads in the model pressure sublevels and the precomputed data for transmission and G-functions. As mentioned in Sec. 4, fluxes are computed at 15 levels ($NP = 15$) and cooling rates for 14 layers. For proper vertical integration of the transfer equations, each layer is further divided into 3 sublayers ($NSB = 3$). Therefore we have 43 sublevels ($NPT = 43$) defining 42 sublayers. The pressure of the first 40 sublevels (PUI) are read in this subroutine and fixed in the model. The last 3 sublevels are computed in subroutine GAMOTO, which depends on the surface pressure.

The G-function is stored in the 3-dimensional array GFH2O. The first index runs from 1 to 25 ($NT = 25$) corresponding to temperatures of 190K ($TEMP1 = 190$) to 310K incremented in steps of 5K ($DT = 5$). The second index corresponding to $\log w$ runs from 1 to 22 ($NW = 22$) where the first value corresponds to $\log w = -6$ ($SW = -6$) for the band center absorption and to -5.4 ($SW = -5.4$) for the band wing absorption. It is incremented in steps of $\Delta \log w = 0.3$ ($DW = 0.3$). The third index corresponding to u runs from 1 to 11 ($NUP1 = 11$). Index values from 1 to 10 refer to the band wing region given at $\Delta u = 0.006$ ($DU = 0.006$) intervals starting from $u = 0$. The last index value is for the band center region which does not include e-type absorption.

The following table summarizes the information in GFH2O (IT, IW, IU) for computing fluxes in the water vapor bands. The units are K for T and gm/cm^2 for w and u .

Table 2
Information in the Precomputed G-Function

Index	Corresponding Parameter	Initial Value		Increment
		Band-Center	Band-Wing	
IT	T	190	190	5
IW	$\log w$	-6.0	-5.4	0.3
IU	u	-	0	0.006

In the $15\mu\text{m}$ band, the CO_2 transmission function, τ_{CO_2} , is stored in TRE as a two-dimensional array. The first index refers to sublevels and the second index to flux levels. The coefficients for the linear expansion, a_i in Eq. (12), are stored in the one-dimensional array FSN only for the region above the 200mb level. FSN is ordered in a way as shown in Fig. 2. Values of TRE and FSN are computed for the U.S. Standard Atmosphere. The transmittance due to water vapor line absorption, τ_w , is stored in TAUW for 65 values of $\log w$ ($\text{NW} = 65$) starting from -4.0 ($\text{SW} = -4$) incremented by 0.1 ($\text{DW} = 0.1$). The transmittance due to e-type absorption, τ_e , is stored in TAUU. Values of TAUU are given at $\Delta \log u = 0.04$ ($\text{DU} = 0.04$) intervals starting from $\log u = -3.301$ ($\text{SU} = -3.301$).

For the $9.6\mu\text{m}$ band, the ozone transmittance, τ_{O_3} , is given by the three-dimensional array, TOZON. The first index refers to sublevels, the second index to flux levels, and the last to

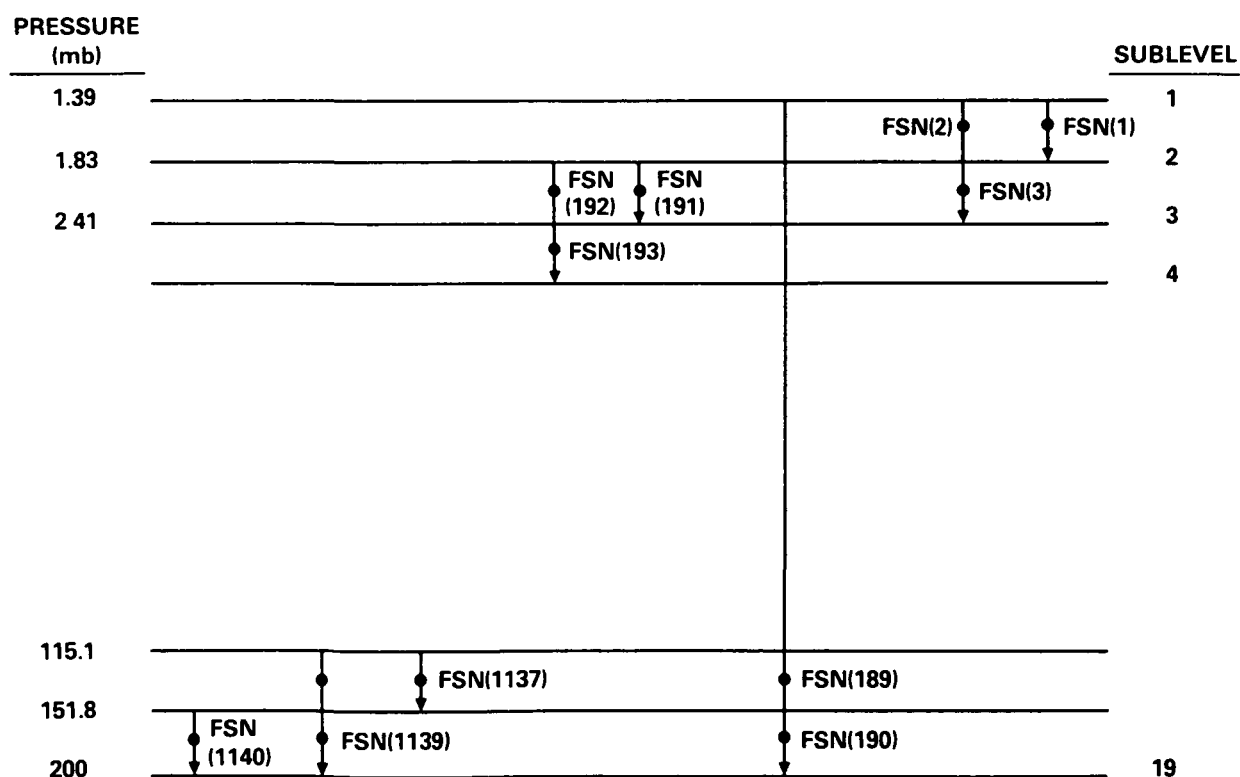


Figure 2. Ordering of the Coefficients FSN's for the Correction of CO_2 Transmittance in the Stratosphere.

latitude zones. In computing ozone transmittance, annual mean ozone mixing ratios representative of 30°-latitude zones are used. The last index (LAT) is equal to 1, 2, and 3 for the latitude zones 0-30, 30-60, and 60-90°, respectively. The transmittance due to e-type absorption, τ_e , is stored in TWIN as a function of log u. It is given at $\Delta \log u = 0.04$ (DU = 0.04) intervals starting from log u = -3.301 (SU = -3.301).

The following table summarizes the information in TAUW, TAUU, and TWIN. The units for w and u are gm/cm².

Table 3

Information in the Precomputed Transmittances due to Water Vapor Absorption

Transmittance	Spectral Band	Index	Corresponding Parameter	Initial Value	Increment
TAUW	15 μ m	IW	log w	-4.0	0.1
TAUU	15 μ m	IU	log u	-3.301	0.04
TWIN	9.6 μ m	IU	log u	-3.301	0.04

c. Subroutine GAMOTO

This subroutine is to

- i) Interpolate user's atmospheric profiles onto the model grids;
- ii) Compute scaled water vapor amounts;
- iii) Compute indices for cloud top and cloud base;
- iv) Call subroutines IRH2O and RCO2O3.

The two sublevels between 900 mb and the surface are computed by dividing the layer into three sublayers with equal Δp , i.e. $\Delta p = (p_s - 900)/3$. The center pressure (PAI) and the air mass (DPI) of each sublayer are then computed. The temperature at each sublevel (TUI) and the temperature and humidity in the middle of each sublayer (TAI and RAWI) are interpolated from the input values of pressure (PA), temperature (TA), and specific humidity (WA). Temperature and the logarithm of the specific humidity are interpolated linearly in $\ln p$. The same parameter

RAWI designated for specific humidity in line 01800 is later redesignated for water vapor content in line 01840.

The scaled water vapor amounts w (WBAR) and u (UBAR) in a column above any pressure level are computed in lines 01910–02000 from the above parameters using Eqs. (17) and (18). The reference pressure p_r is coded as PRE and is equal to 225mb for the band center region and to 550mb for the band wing region. The mean effect of temperature on the absorption coefficient, R , coded as SZ2, is computed from the R -values in Table 1 using a quadratic fit. The coefficients for the quadratic fit are coded as RR. The index KB for the arrays WBAR, RR, and PRE is equal to 1 for the band center absorption and equal to 2 for the band wing absorption. In computing values of u , the following relationship is used

$$\text{eq/g dp} = \left(\frac{p'q}{0.622 P} \right) (1.02 q) dp' = (1.02/630) p'q^2 dp',$$

where the units are dynes/cm² for p and mb for p' , and P is the standard pressure equal to 1013mb. The temperature T_0 in Eq. (18) is equal to 296K.

The pressure corresponding to the cloud levels are changed to the nearest sublevel numbers... of the model grids. The cloud top pressure (CLTOP) is changed to NXT, the cloud base (CLBOT) to NXB, and the cloud amount (CSS) is just redefined to CS.

d. Subroutine IRH2O

This subroutine computes the terms on the right hand sides of Eqs. (3a) and (3b), which are then used in the subroutine FDIVER for computing fluxes in the water vapor bands. The Planck flux is either coded as SH at each sublevels or as FLUXUS at the surface. $G(p, p_t, T(p_t))$ is coded as SHT, $[G(p, p_s, T_s) - G(p, p_s, T(p_s))]$ as SHS, and $(\partial G/\partial T) dT$ as SG. These terms are all computed from the discretized G -values using linear interpolation.

Before discussing the computation of the Planck flux, it is noticed from Eq. (3c) that

$$B(T) = G(w = 0, u = 0, T) = G(w_1, u_1, T) + \delta(T)$$

where w_1 and u_1 are, respectively, the starting values of w and u for the precomputed G -function, and δ (DELTA) the correction term.

The subroutine starts in lines 02560-02670 by interpolating the G -values, corresponding to the surface temperature and the values of w_1 and u_1 , for the band wing region ($NZ = 1$) and the band center region ($NZ = NUP1$). The upward flux at the surface (FLUXUS) is then the sum of the two G -values and the term DELTA. A similar approach is later applied in computing the Planck flux at each sublevel (SH) in lines 03190-03260.

Following the computation of FLUXUS is the computations of the index value for the temperature nearest to the sublevel temperature and the difference between the sublevel temperature and the temperature at the nearest index value. They are stored in IH and DH for later use.

The rest of the subroutine is used to compute SG with SHT and SHS as by-products. Given values of w , u , and T , the G -function is computed from

$$G(w, u, T) = G(w_i, u_j, T_k) + \frac{\partial G}{\partial \log w} (\log w - \log w_i) + \frac{\partial G}{\partial u} (u - u_j) + \frac{\partial G}{\partial T} (T - T_k) \quad (23)$$

where i (KW), j (KU), and k (IT) are the indices for the precomputed G -function nearest to $\log w$, u , and T , respectively. The term $\log w - \log w_i$ is coded as FW, $u - u_j$ as FU, and $T - T_k$ as DH. The computation of G -function using (23) is coded in lines 03030-03080. Values of SG are then computed from Eq. (22) and that of SHS from

$$\begin{aligned} G(w, u, T_s) - G(w, u, T(p_s)) &= \frac{\partial G}{\partial T} (T_s - T(p_s)) \\ &\simeq [G(w_i, u_j, T_{k+1}) - G(w_i, u_j, T_k)] / (T_{k+1} - T_k) \cdot (T_s - T(p_s)). \end{aligned}$$

Values of SG are computed in lines 03080 and 03120, SHT in 03090 and SHS in 03100.

e. Subroutine FDIVER

This subroutine computes upward and downward fluxes in the water vapor bands (FLUXU and FLUXD) from Eqs. (3a) and (3b) using the parameters SH, FLUXUS, SHT, SHS, and SG

computed in the subroutine IRH2O. Treatments of various cloud situations are given in Sec. 4g.

f. Subroutine RCO2O3

This subroutine computes the upward and downward fluxes in the $9.6\mu\text{m}$ band (FLUXUW and FLUXDW), the $15\mu\text{m}$ band (FLUXUC and FLUXDC), and the total in these two absorption bands (FLUXU and FLUXD).

The Planck fluxes integrated over the $9.6\mu\text{m}$ band and the $15\mu\text{m}$ band are interpolated in lines 04340–04470 from the precomputed Planck fluxes. At the middle of each sublayer, the Planck fluxes are coded as BAI for the $15\mu\text{m}$ band and BWI for the $9.6\mu\text{m}$ band. The corresponding Planck fluxes at the surface are coded as BS and BSS, respectively. The precomputed Planck flux in the $9.6\mu\text{m}$ band is stored in BLKWIN and that in the $15\mu\text{m}$ band in BLKCO2 at 5 K intervals starting from 190 K.

The transmittances due to the ozone line absorption (TOZON) and the CO_2 absorption (TRE) are first transferred to the arrays TXUF and TAUF, respectively, in lines 04520–04550. The correction for the CO_2 transmittance above the 200 mb level due to the departure of the temperature profile from the U.S. Standard Atmosphere (TR) is then coded in lines 04570–04780. (Note that no correction is made if the parameter LINEXP is set to FALSE). The transmittance due to water vapor line absorption (X) is computed in lines 04830–04960, and the transmittances due to e-type absorption are computed in lines 04980–05090 for both the $15\mu\text{m}$ band (Y) and the $9.6\mu\text{m}$ band (YY). Finally, the total transmittances are computed from Eqs. (11) and (19) and are coded in lines 05110 and 05120.

With the computed Planck and transmission functions, fluxes in the 9.6 and $15\mu\text{m}$ bands are computed from Eqs. (2a) and (2b) in the rest of the subroutine. The treatments of various clouds are explained below.

g. Treatments of Clouds

Clouds are assumed to be black in the infrared. The routine can be easily extended to a gray cloud with a constant emissivity. It can be shown that a gray cloud with emissivity ϵ and amount C is radiatively equivalent to a black cloud with amount ϵC . Although the radiative transfer equations used for computing fluxes in the water vapor bands and in the 9.6 and 15 μm bands are different, the treatments of clouds are similar. Fig. 3 illustrates an atmosphere with 5 possible cloud situations. The indices NXT and NXB refer to the cloud top and cloud base, respectively, and C the fractional cloud cover. In the H_2O bands, the computation of the downward flux at the pressure level IP is coded in lines 03450-03710 according to the following relationships,

$$\text{FLUXD}(\text{IP}) = \text{SH}(\text{IP}) - \text{SHT}(\text{IP}) + \sum_{I=1}^{\text{IS}-1} \text{SG}(\text{I}, \text{IP})$$

for clear atmospheres or $\text{IS} \leq \text{NXT}$

$$= \text{SH}(\text{IP}) + \sum_{I=\text{NXB}}^{\text{IS}-1} \text{SG}(\text{I}, \text{IP}) \quad \text{for } \text{IS} > \text{NXB}$$

$$= \text{SH}(\text{IP}) \quad \text{for } \text{IS} = \text{NXB} \quad \text{or } \text{NXB} < \text{IS} < \text{NXT}$$

The total flux is the sum of these fluxes weighted by respective fractions of sky cover. For the case shown in Fig. 3, the fraction of the clear sky for the downward flux at IP is $1 - (C_2 + C_3 + C_4)$ which is coded as $1 - \text{SUMC}$.

At each flux level, IP, a one-dimensional array of FLUX is computed from

$$\text{FLUX}(\text{IX}) = \sum_{I=\text{IX}}^{\text{IS}-1} \text{SG}(\text{I}, \text{IP}), \text{IX} = 1, \dots, \text{IS} - 1,$$

which is used for computing fluxes in various cloud situations. Computations of upward fluxes are treated similarly and are not shown here.

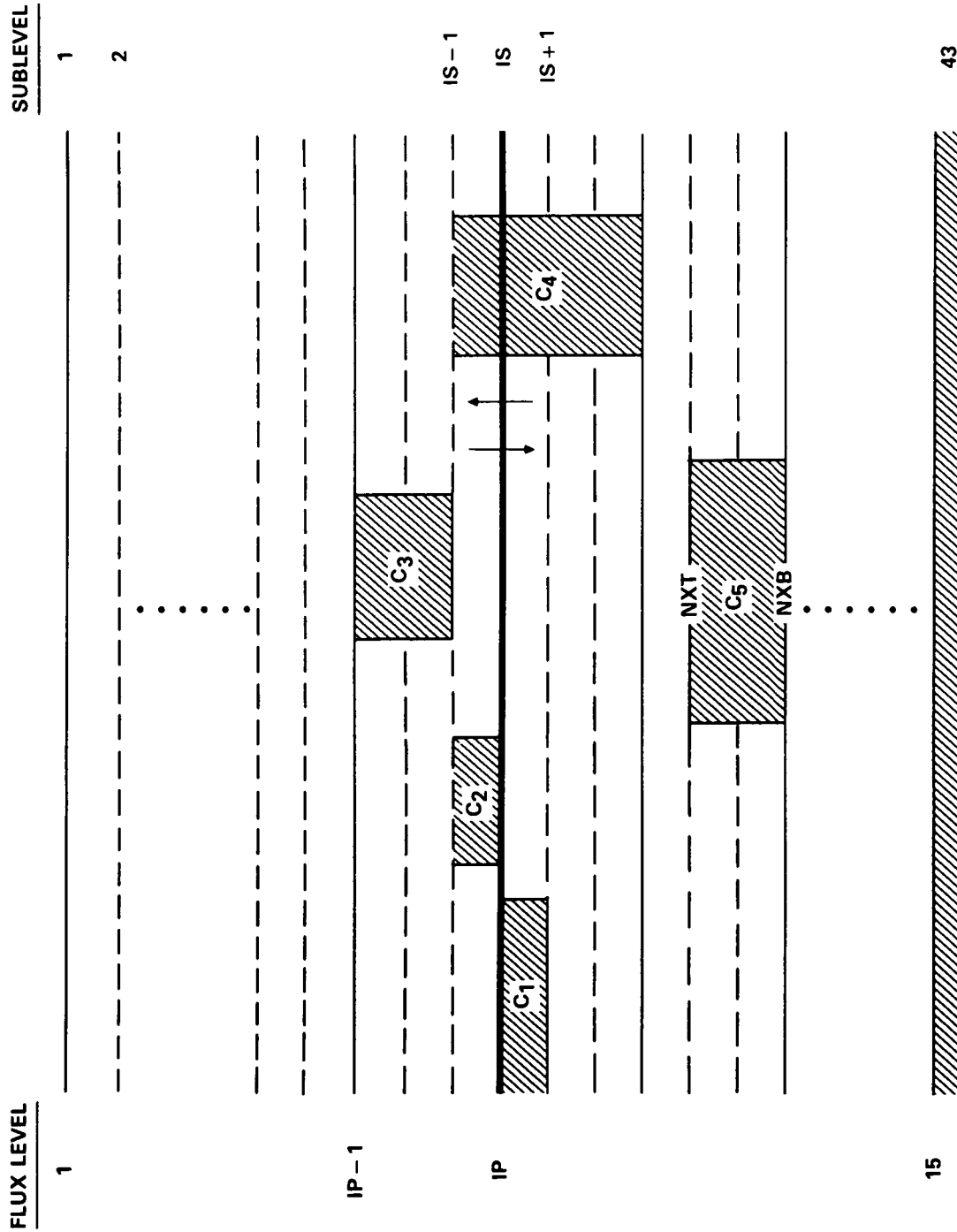


Figure 3. Possible Cloud Situations for Computing Fluxes at the Flux Level IP. NXT and NXB are Indices for Cloud Top and Cloud Base, Respectively, and the C's are Cloud Amount.

With the aid of Fig. 3, the computation of the upward flux in the $15\mu\text{m}$ band coded in lines 05160-05560 is explained below. The upward flux at the level IP is computed from

$$\begin{aligned}
 \text{FLUXUC(IP)} &= \text{BS} * \text{TAUF(NPT, IP)} \\
 &+ \sum_{I=\text{IS}+1}^{\text{NPT}} \text{BAI(I)} * [\text{TAUF(I-1, IP)} - \text{TAUF(I, IP)}] \\
 &\quad \text{for a clear atmosphere or } \text{IS} \geq \text{NXB} \\
 &= \text{BAI(NXT+1)} * \text{TAUF(NXT, IP)} \\
 &+ \sum_{I=\text{IS}+1}^{\text{NXT}} \text{BAI(I)} * [\text{TAUF(I-1, IP)} - \text{TAUF(I, IP)}] \\
 &\quad \text{for } \text{IS} < \text{NXT} \\
 &= \text{BAI(IS+1)} \quad \text{for } \text{IS} = \text{NXT} \text{ or } \text{NXB} < \text{IS} < \text{NXT}
 \end{aligned}$$

An intermediate one-dimensional array FLUXC is computed from

$$\begin{aligned}
 \text{FLUXC(IX)} &= \sum_{I=\text{IS}+1}^{\text{IX}} \text{BAI(I)} * [\text{TAUF(I-1, IP)} - \text{TAUF(I, IP)}], \\
 \text{IX} &= \text{IS} + 1, \dots, \text{NPT}
 \end{aligned}$$

and is used for computing fluxes in different cloud situations. The fraction of clear sky for the case shown in Fig. 3 is $1 - (C_1 + C_4 + C_5)$ and is also coded as $1 - \text{SUMC}$.

6. ACKNOWLEDGMENT

The authors would like to thank Dr. M. L. C. Wu for her critical review of the manuscript and helpful suggestions.

APPENDIX A

PROGRAM LIST

DIMENSION FLUXHU(15),FLUXHD(15),FLUXCU(15),FLUXCD(15)	IR 00010
DIMENSION FXWAV(15),FX15C(15),COOLR(15),PUI(43)	IR 00020
COMMON/FLUXH/FLUXHU,FLUXHD	IR 00030
COMMON/FLUXC/FLUXCU,FLUXCD	IR 00040
COMMON/AMHN/TA(55),PA(55),WA(55),CSS(10),NDATA,RLAT,TS,PS	IR 00050
COMMON/PRESS/PUI	IR 00060
COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT	IR 00070
COMMON/CLOU/CLTOP(10),CLBOT(10)	IR 00080
READ(4,26)NDATA,NC,RLAT,TS,PS	IR 00090
26 FORMAT(I2,2X,I2,2X,F4.2,2X,F5.1,2X,F6.1)	IR 00100
READ(4,32)DUMMY	IR 00110
READ(4,21)(PA(I),I=1,NDATA)	IR 00120
21 FORMAT(5F6.1)	IR 00130
READ(4,32)DUMMY	IR 00140
READ(4,23)(TA(I),I=1,NDATA)	IR 00150
23 FORMAT(8F7.2)	IR 00160
READ(4,32)DUMMY	IR 00170
READ(4,24)(WA(I),I=1,NDATA)	IR 00180
24 FORMAT(5E9.7)	IR 00190
READ(4,32)DUMMY	IR 00200
READ(4,25)(CLTOP(I),CLBOT(I),CSS(I),I=1,5)	IR 00210
25 FORMAT(5(2F4.0,F4.2))	IR 00220
PRINT 10	IR 00230
10 FORMAT(12X,'NDATA',2X,'NC',2X,'RLAT',3X,'TS',6X,'PS')	IR 00240
PRINT 12,NDATA,NC,RLAT,TS,PS	IR 00250
12 FORMAT(13X,I2,4X,I2,2X,F4.1,2X,F5.1,2X,F6.1)	IR 00260
PRINT 14	IR 00270
14 FORMAT(/,10X,'PRESSURE LEVELS(MB) OF SAMPLE PROFILE')	IR 00280
PRINT 15,(PA(I),I=1,NDATA)	IR 00290
15 FORMAT(5(2X,F6.1,6X))	IR 00300
PRINT 16	IR 00310
16 FORMAT(/,10X,'TEMPERATURES(K) AT THE ABOVE PRESSURE LEVELS')	IR 00320
PRINT 11,(TA(I),I=1,NDATA)	IR 00330
11 FORMAT(5(1X,F8.2,5X))	IR 00340
PRINT 17	IR 00350
17 FORMAT(/,10X,'HUMIDITY(GM/GM) AT THE ABOVE PRESSURE LEVELS')	IR 00360
PRINT 13,(WA(I),I=1,NDATA)	IR 00370
13 FORMAT(5(1X,E9.3,4X))	IR 00380
PRINT 19	IR 00390
19 FORMAT(/,10X,'CLOUD TOP',2X,'CLOUD BOTTOM',2X,'CLOUD PERCENT')	IR 00400
PRINT 18,(CLTOP(IC),CLBOT(IC),CSS(IC),IC=1,NC)	IR 00410
18 FORMAT(14X,F4.0,7X,F4.0,9X,F4.2)	IR 00420
32 FORMAT(A1,/,A1)	IR 00430
CALL INDATA	IR 00440
CALL GAMOTO	IR 00450
PRINT 3	IR 00460
3 FORMAT(/,3X,'PRESSURE',4X,'FLUXES IN H2O BANDS',3X,'FLUXES IN 9.	IR 00470
\$6 & 15 MICRON BANDS')	IR 00480
PRINT 4	IR 00490
4 FORMAT(5X,'(MB)',7X,'(ERGS/CM**2/SEC)',11X,'(ERGS/CM**2/SEC)')	IR 00500
PRINT 5	IR 00510
5 FORMAT(15X,'DOWN',8X,'UP',14X,'DOWN',8X,'UP')	IR 00520
DO 2 IP=1,NP	IR 00530
IPM1=IP-1	IR 00540
IDD=(IPM1*NSB)+1	IR 00550
2 PRINT 1,PUI(IDD),FLUXHD(IP),FLUXHU(IP),FLUXCD(IP),FLUXCU(IP)	IR 00560
1 FORMAT(1X,F8.2,2F12.2,4X,2F12.2)	IR 00570
F.C=.6*24./10030.*.98	IR 00580
DO 69 IP=1,NP	IR 00590
FXWAV(IP)=FLUXHD(IP)-FLUXHU(IP)	IR 00600

69	FX15C(IP)=FLUXCD(IP)-FLUXCU(IP)	IR 00610
	PRINT 6	IR 00620
6	FORMAT(//16X,'PRESSURE',10X,'COOLING RATE',	IR 00630
	PRINT 7	IR 00640
7	FORMAT(16X,'(MBAR)',7X,'(DEGREE CELCIUS/DAY)',	IR 00650
	PRINT 8	IR 00660
8	FORMAT(12X,'FROM',6X,'TO',	IR 00670
	DO 90 IP=2,NP	IR 00680
	IPM1=IP-1	IR 00690
	IDD=(IPM1*NSB)+1	IR 00700
	IDE=IDD-NSB	IR 00710
	DP=PUI(IDD)-PUI(IDE)	IR 00720
	X1=FXWAV(IP)+FX15C(IP)	IR 00730
	X2=FXWAV(IPM1)+FX15C(IPM1)	IR 00740
	FXNET=X1-X2	IR 00750
	COOLR(IP)=FXNET*FAC/DP	IR 00760
90	CONTINUE	IR 00770
	DO 92 IP=2,NP	IR 00780
	IPM1=IP-1	IR 00790
	IDD=(IPM1*NSB)+1	IR 00800
	IDE=IDD-NSB	IR 00810
92	PRINT 91,PUI(IDE),PUI(IDD),COOLR(IP)	IR 00820
91	FORMAT(10X,2F8.2,4X,F10.2)	IR 00830
	STOP	IR 00840
	END	IR 00850

SUBROUTINE INDATA	IR 00860
C*** READ IN DATA	IR 00870
DIMENSION GFH20(25,22,11),TRE(43,15)	IR 00880
DIMENSION TAUW(65),TWIN(100),TAUU(100),ITX(50)	IR 00890
DIMENSION TOZON(43,15,3),PUI(43)	IR 00900
DIMENSION ISN(1140),FSN(1140)	IR 00910
COMMON/H2O/GFH20	IR 00920
COMMON/PRESS/PUI	IR 00930
COMMON/CO2/TAUW,TAUJ,TOZON,TWIN,TRE,FSN	IR 00940
COMMON/INIT/NUPI,NP,NSB,NC,NPT,NW,NT	IR 00950
NUPI=11	IR 00960
NP=15	IR 00970
NPT=43	IR 00980
NW=22	IR 00990
NSB=3	IR 01000
NT=25	IR 01010
READ(5,32)DUMMY	IR 01020
READ(5,32)DUMMY	IR 01030
READ(5,31)(PUI(IX),IX=1,40)	IR 01040
31 FORMAT(9F8.3)	IR 01050
READ(5,32)DUMMY	IR 01060
32 FORMAT(A1,/,A1,/)	IR 01070
DO 30 IU=1,NUPI	IR 01080
DO 30 IW=1,NW	IR 01090
READ(5,35)(ITX(IT),IT=1,NT)	IR 01100
35 FORMAT(13I6)	IR 01110
DO 40 IT=1,NT	IR 01120
GFH20(IT,IW,IU)=ITX(IT)	IR 01130
40 CONTINUE	IR 01140
30 CONTINUE	IR 01150
READ(5,32)DUMMY	IR 01160
DO 41 IP=1,NP	IR 01170
READ(5,42)(ITX(IX),IX=1,NPT)	IR 01180
42 FORMAT(24I3)	IR 01190
DO 43 IX=1,NPT	IR 01200
43 TRE(IX,IP)=ITX(IX)/1000.	IR 01210
41 CONTINUE	IR 01220
READ(5,32)DUMMY	IR 01230
READ(5,45)(ISN(I),I=1,1140)	IR 01240
45 FORMAT(40I2)	IR 01250
DO 50 I=1,1140	IR 01260
F=ISN(I)	IR 01270
50 FSN(I)=-1.E-5*F	IR 01280
C*** READ TAUW,TAUU	IR 01290
READ(5,32)DUMMY	IR 01300
READ(5,81)(TAUW(IW),IW=1,65)	IR 01310
READ(5,32)DUMMY	IR 01320
READ(5,81)(TAUU(IU),IU=1,100)	IR 01330
81 FORMAT(10F8.5)	IR 01340
READ(5,32)DUMMY	IR 01350
READ(5,10)((TOZON(IX,IP,LAT),IP=1,NP,IX=1,NPT),LAT=1,3)	IR 01360
10 FORMAT(15F5.3)	IR 01370
READ(5,32)DUMMY	IR 01380
READ(5,1)(TWIN(IU),IU=1,100)	IR 01390
1 FORMAT(20F4.2)	IR 01400
RETURN	IR 01410
END	IR 01420

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SUBROUTINE GAMOTO	IR 01430
DIMENSION RR(2,3),PRE(2,	IR 01440
DIMENSION NXT(10),NXB(10),CS(10)	IR 01450
DIMENSION PUI(43),TUI(43),PAI(43),RAWI(43),DPI(43),TAI(43)	IR 01460
COMMON/CLOUD/CS,NXB,NXT	IR 01470
COMMON/TEMP/TSS	IR 01480
COMMON/PRESS/PUI	IR 01490
COMMON/CLOU/CLTOP(10),CLBOT(10)	IR 01500
COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT	IR 01510
COMMON/AGIOS/TUI,PAI,TAI,RAWI,UBAR(43),WBAR(2,43)	IR 01520
COMMON/AMHN/TA(55),PA(55),WA(55),CSS(10),NDATA,RLAT,TS,PS	IR 01530
DATA PRE/275.,550./	IR 01540
DATA RR/1.216414,4.62111,-0.517625E-2,-0.4321E-1,0.1875E-4,	IR 01550
\$.11344E-3/	IR 01560
TSS=TS	IR 01570
DP=(PS-PUI(40))/3.	IR 01580
DO 10 IX=41,43	IR 01590
10 PUI(IX)=PUI(IX-1)+DP	IR 01600
DO 1010 IX=2,NPT	IR 01610
DPI(IX)=(PUI(IX)-PUI(IX-1))*1.02	IR 01620
PAI(IX)=0.5*(PUI(IX)+PUI(IX-1))	IR 01630
1010 CONTINUE	IR 01640
C	IR 01650
C***** TEMPERATURE AND HUMIDITY INTERPOLATIONS *****	IR 01660
C	IR 01670
NCK=2	IR 01680
DO 1030 IX=2,NPT	IR 01690
1040 IF(PAI(IX) .LT. PA(NCK)) GO TO 1042	IR 01700
IF(NCK .EQ. NDATA) GO TO 1042	IR 01710
NCK=NCK+1	IR 01720
GO TO 1040	IR 01730
1042 CONTINUE	IR 01740
XX=ALOG(WA(NCK-1))	IR 01750
X1=ALOG(PAI(IX)/PA(NCK-1))	IR 01760
X2=ALOG(PUI(IX)/PA(NCK-1))	IR 01770
X3=ALOG(WA(NCK)/WA(NCK-1))	IR 01780
X4=ALOG(PA(NCK)/PA(NCK-1))	IR 01790
RAWI(IX)=EXP(XX+X1*X3/X4)	IR 01800
IF (RAWI(IX) .LT. 0.0) RAWI(IX)=0.0	IR 01810
TAI(IX)=TA(NCK-1)+X1/X4*(TA(NCK)-TA(NCK-1))	IR 01820
TUI(IX)=TA(NCK-1)+X2/X4*(TA(NCK)-TA(NCK-1))	IR 01830
RAWI(IX)=RAWI(IX)*DPI(IX)	IR 01840
1030 CONTINUE	IR 01850
TAI(1)=TAI(2)	IR 01860
TUI(1)=TAI(2)	IR 01870
C	IR 01880
C***** COMPUTE SCALED WATER VAPOR AMOUNTS *****	IR 01890
C	IR 01900
UBAR(1)=0.	IR 01910
WBAR(1,1)=0.0	IR 01920
WBAR(2,1)=0.0	IR 01930
DO 14 IX=2,NPT	IR 01940
DO 12 KB=1,2	IR 01950
SZ2=RR(KB,1)+RR(KB,2)*TAI(IX)+RR(KB,3)*TAI(IX)*TAI(IX)	IR 01960
12 WBAR(KB,IX)=WBAR(KB,IX-1)+RAWI(IX)*SZ2*(PAI(IX)/PRE(KB))	IR 01970
XX=(PAI(IX)/630.)*RAWI(IX)*RAWI(IX)/DPI(IX)	IR 01980
XX=XX*EXP(1800./TAI(IX)-6.0811)	IR 01990
14 UBAR(IX)=UBAR(IX-1)+XX	IR 02000

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C	IR 02010
C***** COMPUTE INDEX LEVELS FOR CLOUDS *****	IR 02020
C	IR 02030
DO 20 IC=1,NC	IR 02040
20 CS(IC)=CSS(IC)	IR 02050
DO 3 IC=1,NC	IR 02060
DO 2 IX=16,42	IR 02070
IF(PUI(IX).LE.CLTOP(IC).AND.PUI(IX+1).GE.CLTOP(IC),GOTO 4	IR 02080
5 IF(PUI(IX).LE.CLBOT(IC).AND.PUI(IX+1).GE.CLBOT(IC),GOTO 6	IR 02090
GOTO 2	IR 02100
4 UT=CLTOP(IC)-PUI(IX)	IR 02110
UB=PUI(IX+1)-CLTOP(IC)	IR 02120
IF(UT.LT.UB,GOTO 7	IR 02130
NXT(IC)=IX+1	IR 02140
GOTO 5	IR 02150
7 NXT(IC)=IX	IR 02160
GOTO 5	IR 02170
6 UT=CLBOT(IC)-PUI(IX)	IR 02180
UB=PUI(IX+1)-CLBOT(IC)	IR 02190
IF(UT.LT.UB,GOTO 8	IR 02200
NXB(IC)=IX+1	IR 02210
GOTO 2	IR 02220
8 NXB(IC)=IX	IR 02230
2 CONTINUE	IR 02240
3 CONTINUE	IR 02250
CALL IRH20	IR 02260
CALL RCO203(RLAT)	IR 02270
RETURN	IR 02280
END	IR 02290

SUBROUTINE IRH20	IR 02300
DIMENSION IH(43),DH(43),SW(2)	IR 02310
DIMENSION GFH20(25,22,11),DELTA(25)	IR 02320
DIMENSION SG(43,15),SH(15),SHT(15),SHS(15)	IR 02330
DIMENSION RAWI(43),TAI(43),PAI(43),TUI(43)	IR 02340
COMMON/AGIOS/TUI,PAI,TAI,RAWI,UBAR(43),WBAR(2,43)	IR 02350
COMMON/H20/GFH20	IR 02360
COMMON/TEMP/TS	IR 02370
COMMON/INIT/NUPI,NP,NSB,NC,NPT,NW,NT	IR 02380
COMMON/FDIV/SH,SG,SHT,SHS,FLUXUS	IR 02390
DATA TEMPI/190./,SW/-6.,-5.4/	IR 02400
DATA DW/0.3/,DU/0.006/,DT/5./	IR 02410
DATA DELTA/160.,168.,179.,189.,199.,211.,219.,232.,242.,254.,	IR 02420
\$268.,279.,292.,307.,320.,335.,350.,365.,382.,397.,415.,	IR 02430
\$432.,451.,471.,492./	IR 02440
NU=NUPI-1	IR 02450
C*** COMPUTE SHS,SHT,SG	IR 02460
FLUXUS=0.	IR 02470
DO 43 IP=1,NP	IR 02480
SH(IP)=0.	IR 02490
SHS(IP)=0.	IR 02500
SHT(IP)=0.	IR 02510
DO 44 IX=1,NPT	IR 02520
SG(IX,IP)=0.	IR 02530
44 CONTINUE	IR 02540
43 CONTINUE	IR 02550
FH=(TS-TEMPI)/DT+1.501	IR 02560
IG=FH	IR 02570
IF(IG .GE. NT) IG=NT-1	IR 02580
IF(IG .LT. 1) IG=1	IR 02590
DS=TS-(TEMPI+FLOAT(IG-1)*DT)	IR 02600
NZ=1	IR 02610
DO 41 KB=1,2	IR 02620
X=GFH20(IG,1,NZ)+(GFH20(IG+1,1,NZ)-GFH20(IG,1,NZ))/DT*DS	IR 02630
FLUXUS=FLUXUS+X	IR 02640
NZ=NUPI	IR 02650
41 CONTINUE	IR 02660
FLUXUS=FLUXUS+DELTA(IG)	IR 02670
DO 47 IX=1,NPT	IR 02680
FH=(TUI(IX)-TEMPI)/DT+1.5	IR 02690
IH(IX)=FH	IR 02700
IF(IH(IX) .LT. 1) IH(IX)=1	IR 02710
IF(IH(IX) .GE. NT) IH(IX)=NT-1	IR 02720
F1=IH(IX)-1	IR 02730
DH(IX)=TUI(IX)-(TEMPI+F1*DT)	IR 02740
47 CONTINUE	IR 02750
DO 42 IP=1,NP	IR 02760
IS=(IP-1)*NSB+1	IR 02770
DO 40 IX=1,NPT	IR 02780
IF(IX.EQ.IX)GOTO 40	IR 02790
IF(IX .LT. IS) IC=IX+1	IR 02800
IF(IX .GT. IS) IC=IX-1	IR 02810
DY=ABS(UBAR(IS)-0.5*(UBAR(IC)+UBAR(IX)))	IR 02820
KU=DY/DU+1.5	IR 02830
IF(KU .GE. NU) KU=NU-1	IR 02840
FU=DY-FLOAT(KU-1)*DU	IR 02850

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C***	KB=1, FOR BAND CENTER REGION, KB=2, FOR BAND WING REGION	IR 02860
	DO 45 KB=1,2	IR 02870
	DX=ABS(WBAR(KB,1S,-0.5*(WBAR(KB,IC)+WBAR(KB,IX)))	IR 02880
	IF(DX.GT. 30.) GO TO 40	IR 02890
	IF(DX.LT. 1.E-6, DX=1.E-6	IR 02900
	DX=ALOG10(DX)	IR 02910
	IF(DX.LT.SW(KB),DX=SW(KB)	IR 02920
	KW=(D)-SW(KB)/DW+1.5001	IR 02930
	IF(KW.GE. NW) KW=NW-1	IR 02940
	FW=DX-(SW(KB)+FLOAT(KW-1)*DW)	IR 02950
	NZ=NUPI	IR 02960
	IF(KB.EQ. 2, NZ=KU	IR 02970
	IK=IX	IR 02980
	DO 50 I=1,2	IR 02990
	IF (I.EQ. 2) IK=IC	IR 03000
	IT=IH(IK)	IR 03010
	DH1=DH(IK)	IR 03020
	DGDT=(GFH20(IT+1,KW,NZ)-GFH20(IT,KW,NZ))/DT	IR 03030
	TDEL=DGDT*DH1	IR 03040
	WDEL=(GFH20(IT,KW+1,NZ)-GFH20(IT,KW,NZ))/DW*FW	IR 03050
	IF(KB.EQ.2,WDEL=WDEL+(GFH20(IT,KW,NZ+1)-GFH20(IT,KW,NZ))	IR 03060
	*DU*FU	IR 03070
	X=GFH20(IT,KW,NZ)+TDEL+WDEL	IR 03080
	IF(IK.EQ.1)SHT(IP)=SHT(IP)+X	IR 03090
	IF(IK.EQ.NPT)SHS(IP)=SHS(IP)+DGDT*(TS-TUI(NPT))	IR 03100
	IF (I.EQ.2) X=-X	IR 03110
	SG(IX,IP)=SG(IX,IP)+X	IR 03120
50	CONTINUE	IR 03130
45	CONTINUE	IR 03140
40	CONTINUE	IR 03150
C		IR 03160
C*****	COMPUTE SH(IP)	IR 03170
C		IR 03180
	IT=IH(1S)	IR 03190
	NZ=1	IR 03200
	DO 46 KB=1,2	IR 03210
	X=GFH20(IT,1,NZ)+(GFH20(IT+1,1,NZ)-GFH20(IT,1,NZ))/DT*DH(1S)	IR 03220
	SH(IP)=SH(IP)+X	IR 03230
	NZ=NUPI	IR 03240
46	CONTINUE	IR 03250
	SH(IP)=SH(IP)+DELTA(IT)	IR 03260
42	CONTINUE	IR 03270
	CALL FDIVER	IR 03280
	RETURN	IR 03290
	END	IR 03300

SUBROUTINE FDIVER	IR 03310
DIMENSION FLUXU(15),FLUXD(15),FLUX(43)	IR 03320
DIMENSION SHT(15),SHS(15),SH(15),SG(43,15)	IR 03330
DIMENSION CS(10),NXB(10),NXT(10)	IR 03340
COMMON/CLOUD/CS,NXB,NXT	IR 03350
COMMON/INIT/NUPI,NP,NSB,NC,NPT,NW,NT	IR 03360
COMMON/FDIV/SH,SG,SHT,SHS,FLUXUS	IR 03370
COMMON/FLUXH/FLUXU,FLUXD	IR 03380
NPM1=NP-1	IR 03390
DO 100 I=1,NP	IR 03400
FLUXU(I)=0.	IR 03410
FLUXD(I)=0.	IR 03420
100 CONTINUE	IR 03430
C*** COMPUTE DOWNWARD FLUXES	IR 03440
DO 185 IP=2,NP	IR 03450
IS=(IP-1)*NSB+1	IR 03460
ISM1=IS-1	IR 03470
SUM=0.	IR 03480
DO 190 LP=1,ISM1	IR 03490
IX=IS-LP	IR 03500
SUM=SUM+SG(IX,IP)	IR 03510
FLUX(IX)=SUM	IR 03520
190 CONTINUE	IR 03530
FLUX(1)=FLUX(1)-SHT(IP)+SH(IP)	IR 03540
IF(NC.NE.0)GOTO 75	IR 03550
FLUXD(IP)=FLUX(1)	IR 03560
GOTO 185	IR 03570
75 CONTINUE	IR 03580
SUMC=0.	IR 03590
DO 60 IC=1,NC	IR 03600
NCBX=NXB(IC)	IR 03610
IF(IS.LE.NXT(IC),GOTO 60	IR 03620
IF(IS.LE.NCBX)GOTO 62	IR 03630
FLUXD(IP)=FLUXD(IP)+(FLUX(NCBX)+SH(IP))*CS(IC)	IR 03640
GOTO 63	IR 03650
62 CONTINUE	IR 03660
FLUXD(IP)=FLUXD(IP)+SH(IP)*CS(IC)	IR 03670
63 SUMC=SUMC+CS(IC)	IR 03680
60 CONTINUE	IR 03690
FLUXD(IP)=FLUXD(IP)+FLUX(1)*(1.-SUMC)	IR 03700
185 CONTINUE	IR 03710
C*** COMPUTE UPWARD FLUXES	IR 03720
DO 200 IP=1,NPM1	IR 03730
IS=(IP-1)*NSB+1	IR 03740
ISP1=IS+1	IR 03750
SUM=0.	IR 03760
DO 205 IX=ISP1,NPT	IR 03770
SUM=SUM+SG(IX,IP)	IR 03780
FLUX(IX)=SUM	IR 03790
205 CONTINUE	IR 03800
FLUX(NPT)=FLUX(NPT)+SHS(IP)+SH(IP)	IR 03810
IF(NC.NE.0)GOTO 76	IR 03820
FLUXU(IP)=FLUX(NPT)	IR 03830
GOTO 200	IR 03840
76 CONTINUE	IR 03850

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SUMC=0.	IR 03860
DO 70 IC=1,NC	IR 03870
NCTX=NXT(IC)	IR 03880
IF(IS.GE.NXB(IC),GOTO 70	IR 03890
IF(IS.GE.NCTX,GOTO 72	IR 03900
FLUXU(IP)=FLUXU(IP)+(FLUX(NCTX)+SH(IP))*CS(IC)	IR 03910
GOTO 73	IR 03920
72 CONTINUE	IR 03930
FLUXU(IP)=FLUXU(IP)+SH(IP)*CS(IC)	IR 03940
73 SUMC=SUMC+CS(IC)	IR 03950
70 CONTINUE	IR 03960
FLUXU(IP)=FLUXU(IP)+FLUX(NPT)*(1.-SUMC)	IR 03970
200 CONTINUE	IR 03980
FLUXU(NP)=FLUXUS	IR 03990
RETURN	IR 04000
END	IR 04010

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SUBROUTINE RCO203(RLAT,
DIMENSION PAI(43),TAI(43),RAWI(43),BAI(44)
DIMENSION TUI(43),TOZON(43,15,3)
DIMENSION TAUU(100),TWIN(100),TAUW(65)
DIMENSION BWI(44),BLKWIN(25),BLKCO2(25)
DIMENSION TRE(43,15),TAUF(43,15),TXUF(43,15)
DIMENSION FLUXD(15),FLUXU(15),FLUXC(43),FLUXW(43)
DIMENSION FLUXDC(15),FLUXDW(15),FLUXUC(15),FLUXUW(15)
DIMENSION CS(10),NXB(10),NXT(10)
DIMENSION TR(19),DTAI(19),DTF(19,19),FSN(1140)
COMMON/TEMP/TS
COMMON/FLUXC/FLUXU,FLUXD
COMMON/CLOUD/CS,NXB,NXT
COMMON/AGIOS/TUI,PAI,TAI,RAWI,UBAR(43),WBAR(2,43)
COMMON/CO2/TAUW,TAUU,TOZON,TWIN,TRE,FSN
COMMON/INIT/NUP1,NP,NSB,NC,NPT,NW,NT
DATA TR/266.6,262.82,257.13,251.35,245.54,239.95,234.54,
$229.81,227.06,225.19,223.38,221.6,219.8,218.05,216.49,
$4*216.65/
DATA BLKCO2/12825., 14598., 16512., 18568., 20768., 23113.,
1 25603., 28237., 31015., 33937., 37001., 40207., 43552.,
2 47036., 50656., 54412., 58300., 62318., 66465., 70738.,
3 75136., 79655., 84293., 89048., 93918./
DATA BLKWIN/1944.,2377.,2877.,3450.,4102.,4838.,5664.,6585.,
* 7606.,8733.,9969.,11320.,12788.,14380.,16097.,
* 17944.,19923.,22038.,24292.,26685.,29221.,31902.,
* 34729.,37703.,40825./
DATA SW/-4./,DW/0.1/,NK/65/,SU/-3.301/,DU/.04/
DATA TEMP1/190./,DT/5.0/
LOGICAL LINEXP/.TRUE./
NPTP1=NPT+1
LAT=IFIX(RLAT/30.+1.)
TAI(NPTP1)=TS
DO 15 IP=1,NPTP1
DX=TAI(IP)-TEMP1
IT=DX/DT+1.5
IF(IT.LT. 2) IT=2
IF(IT.GT. NT) IT=NT
ITM1=IT-1
X=TEMP1+DT*FLOAT(ITM1)
DS=TAI(IP)-X
BAI(IP)=BLKCO2(IT)+(BLKCO2(IT)-BLKCO2(ITM1))*DS/DT
BWI(IP)=BLKWIN(IT)+(BLKWIN(IT)-BLKWIN(ITM1))*DS/DT
15 CONTINUE
BS=BAI(NPTP1)
BSS=BWI(NPTP1)
C
C***** COMPUTE TRANSMITTANCES IN THE 15 MICRON(TAUF) AND
C***** 9.6 MICRON (TXUF) BANDS.
C
DO 25 IP=1,NP
DO 25 LP=1,NPT
TXUF(LP,IP)=TOZON(LP,IP,LAT)
25 TAUF(LP,IP)=TRE(LP,IP)
IF(.NOT.LINEXP)GOTO 23
NSTRA=19
NSM1=NSTRA-1
DO 21 LP=1,NSTRA
21 DTAI(LP)=TAI(LP)-TR(LP)
LL=0
DO 20 LP=1,NSM1
LPP1=LP+1
DO 20 IX=LPP1,NSTRA
SUM=0.
IY=IX-LP

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IR 04020
IR 04030
IR 04040
IR 04050
IR 04060
IR 04070
IR 04080
IR 04090
IR 04100
IR 04110
IR 04120
IR 04130
IR 04140
IR 04150
IR 04160
IR 04170
IR 04180
IR 04190
IR 04200
IR 04210
IR 04220
IR 04230
IR 04240
IR 04250
IR 04260
IR 04270
IR 04280
IR 04290
IR 04300
IR 04310
IR 04320
IR 04330
IR 04340
IR 04350
IR 04360
IR 04370
IR 04380
IR 04390
IR 04400
IR 04410
IR 04420
IR 04430
IR 04440
IR 04450
IR 04460
IR 04470
IR 04480
IR 04490
IR 04500
IR 04510
IR 04520
IR 04530
IR 04540
IR 04550
IR 04560
IR 04570
IR 04580
IR 04590
IR 04600
IR 04610
IR 04620
IR 04630
IR 04640
IR 04650
IR 04660

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DO 22 L=1,IY	IR 04670
LL=LL+1	IR 04680
SUM=SUM+FSN(LL,*DTAI(LP+L)	IR 04690
22 CONTINUE	IR 04700
DTF(IX,LP)=SUM	IR 04710
DTF(LP,IX)=SUM	IR 04720
20 CONTINUE	IR 04730
DO 23 IP=1,7	IR 04740
IX=(IP-1)*NSB+1	IR 04750
DO 24 LP=1,NSTRA	IR 04760
24 TAUFL(LP,IP)=TAUFL(LP,IP)+DTF(LP,IX)	IR 04770
23 CONTINUE	IR 04780
DO 28 IP=1,NP	IR 04790
IS=(IP-1)*NSB+1	IR 04800
DO 32 IX=1,NPT	IR 04810
IF(IS.EQ. IX) GO TO 32	IR 04820
DX=ABS(WBAR(2,IS)-WBAR(2,IX))	IR 04830
IF(DX.LT.1.E-7)DX=1.E-7	IR 04840
IF(DX.LT. 40.) GO TO 35	IR 04850
X=0.	IR 04860
YY=0.	IR 04870
GO TO 40	IR 04880
35 CONTINUE	IR 04890
DX=ALOG10(DX)	IR 04900
IF(DX.LT. SW) GO TO 34	IR 04910
KW=(DX-SW)/DW+1.5	IR 04920
IF(KW.GT. NK) KW=NK	IR 04930
X=TAUW(KW)	IR 04940
GO TO 36	IR 04950
34 X=1.	IR 04960
36 CONTINUE	IR 04970
DX=ABS(UBAR(IS)-UBAR(IX))	IR 04980
IF (DX.LT.1.E-7) GO TO 38	IR 04990
DX=ALOG10(DX)	IR 05000
IF(DX.LT. SU) GO TO 38	IR 05010
KU=(DX-SU)/DU+1.5	IR 05020
IF(KU.GT. 100) KU=100	IR 05030
Y=TAUU(KU)	IR 05040
YY=TWIN(KU)	IR 05050
GO TO 40	IR 05060
38 CONTINUE	IR 05070
Y=1.	IR 05080
YY=1.	IR 05090
40 CONTINUE	IR 05100
TAUFL(IX,IP)=TAUFL(IX,IP)*X*Y	IR 05110
TXUFL(IX,IP)=TXUFL(IX,IP)*YY	IR 05120
32 CONTINUE	IR 05130
28 CONTINUE	IR 05140
C*** COMPUTE DOWNWARD FLUXES	IR 05150
FLUXDC(1)=0.	IR 05160
FLUXDW(1)=0.	IR 05170
DO 70 IP=2,NP	IR 05180
FLUXDC(IP)=0.	IR 05190
FLUXDW(IP)=0.	IR 05200
TAI=1.	IR 05210
TAYY=1.	IR 05220
IS=(IP-1)*NSB+1	IR 05230
ISM1=IS-1	IR 05240
XC=0.	IR 05250
XW=0.	IR 05260

DO 75 LP=1,ISM1	IR 05270
IX=IS-LP	IR 05280
XC=XC+BAI(IX+1)*(TAY-TAUF(IX,IP))	IR 05290
XW=XW+BWI(IX+1)*(TAYY-TXUF(IX,IP))	IR 05300
FLUXC(IX)=XC	IR 05310
FLUXW(IX)=XW	IR 05320
TAY=TAUF(IX,IP)	IR 05330
TAYY=TXUF(IX,IP)	IR 05340
75 CONTINUE	IR 05350
IF(NC.NE.0)GOTO 69	IR 05360
FLUXDC(IP)=FLUXC(1)	IR 05370
FLUXDW(IP)=FLUXW(1)	IR 05380
GOTO 70	IR 05390
69 CONTINUE	IR 05400
SUMC=0.	IR 05410
DO 60 IC=1,NC	IR 05420
NCBX=NXB(IC)	IR 05430
IF(IS.LE.NXT(IC))GOTO 60	IR 05440
IF(IS.LE.NCBX)GOTO 62	IR 05450
FLUXDC(IP)=FLUXDC(IP)+(FLUXC(NCBX)+BAI(NCBX)*TAUF(NCBX,IP))*CS(IC)	IR 05460
FLUXDW(IP)=FLUXDW(IP)+(FLUXW(NCBX)+BWI(NCBX)*TXUF(NCBX,IP))*CS(IC)	IR 05470
GOTO 63	IR 05480
62 CONTINUE	IR 05490
FLUXDC(IP)=FLUXDC(IP)+BAI(IS)*CS(IC)	IR 05500
FLUXDW(IP)=FLUXDW(IP)+BWI(IS)*CS(IC)	IR 05510
63 SUMC=SUMC+CS(IC)	IR 05520
60 CONTINUE	IR 05530
FLUXDC(IP)=FLUXDC(IP)+FLUXC(1)*(1.-SUMC)	IR 05540
FLUXDW(IP)=FLUXDW(IP)+FLUXW(1)*(1.-SUMC)	IR 05550
70 CONTINUE	IR 05560
C*** COMPUTE UPWARD FLUXES	IR 05570
NPM1=NP-1	IR 05580
DO 80 IP=1,NPM1	IR 05590
FLUXJC(IP)=0.	IR 05600
FLUXJW(IP)=0.	IR 05610
TAY=1.	IR 05620
TAYY=1.	IR 05630
IS=(IP-1)*NSB+1	IR 05640
ISP1=IS+1	IR 05650
XC=0.	IR 05660
XW=0.	IR 05670
DO 5 IX=ISP1,NPT	IR 05680
XC=XC+BAI(IX)*(TAY-TAUF(IX,IP))	IR 05690
XW=XW+BWI(IX)*(TAYY-TXUF(IX,IP))	IR 05700
FLUXC(IX)=XC	IR 05710
FLUXW(IX)=XW	IR 05720
TAY=TAUF(IX,IP)	IR 05730
TAYY=TXUF(IX,IP)	IR 05740
85 CONTINUE	IR 05750
FLUXC(NPT)=FLUXC(NPT)+BS*TAY	IR 05760
FLUXW(NPT)=FLUXW(NPT)+BSS*TAYY	IR 05770
IF(NC.NE.0)GOTO 68	IR 05780
FLUXJC(IP)=FLUXC(NPT)	IR 05790
FLUXJW(IP)=FLUXW(NPT)	IR 05800
GOTO 80	IR 05810
68 CONTINUE	IR 05820
SUMC=0.	IR 05830
DO 64 IC=1,NC	IR 05840
NCTX=NXT(IC)	IR 05850
IF(IS.GE.NXB(IC))GOTO 64	IR 05860
IF(IS.GE.NCTX)GOTO 66	IR 05870

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FLUXUC(IP)=FLUXUC(IP)+(FLUXC(NCTX)+BAI(NCTX+1)*TAUF(NCTX,IP))	IR 05880
1*CS(IC)	IR 05890
FLUXUW(IP)=FLUXUW(IP)+(FLUXW(NCTX)+BWI(NCTX+1)*TXUF(NCTX,IP)	IR 05900
1)*CS(IC)	IR 05910
GOTO 67	IR 05920
66 CONTINUE	IR 05930
FLUXUC(IP)=FLUXUC(IP)+BAI(IS+1)*CS(IC)	IR 05940
FLUXUW(IP)=FLUXUW(IP)+BWI(IS+1)*CS(IC)	IR 05950
67 SUMC=SUMC+CS(IC)	IR 05960
64 CONTINUE	IR 05970
FLUXUC(IP)=FLUXUC(IP)+FLUXC(NPT)*(1.-SUMC)	IR 05980
FLUXUW(IP)=FLUXUW(IP)+FLUXW(NPT)*(1.-SUMC)	IR 05990
80 CONTINUE	IR 06000
FLUXUC(NP)=BS	IR 06010
FLUXUW(NP)=BSS	IR 06020
C	IR 06030
C***** TOTAL FLUXES IN THE 9.6 AND 15 MICRON BANDS *****	IR 06040
C	IR 06050
DO 97 IP=1,NP	IR 06060
FLUXU(IP)=FLUXUC(IP)+FLUXUW(IP)	IR 06070
FLUXD(IP)=FLUXDC(IP)+FLUXDW(IP)	IR 06080
97 CONTINUE	IR 06090
RETURN	IR 06100
END	IR 06110

APPENDIX B
ARRAY AND VARIABLE LIST

1. Main Program

Code	Meaning	Unit
PA	Input pressure level	mb
TA	Input temperature	K
WA	Input specific humidity	gm/gm
CLTOP	Cloud top pressure	mb
CLBOT	Cloud base pressure	mb
CSS	Fractional cloud amount	
NDATA	Number of input data in PA, TA, WA	
NC	Number of cloud types	
RLAT	Latitude	degree
PS	Surface pressure	mb
TS	Surface temperature	K
PUI	Pressure sublevel	mb
FLUXHD	Downward flux in the H ₂ O bands	ergs/(cm ² sec)
FLUXHU	Upward flux in the H ₂ O bands	ergs/(cm ² sec)
FLUXCD	Downward flux in the 9.6 and 15 μ m bands	ergs/(cm ² sec)
FLUXCU	Upward flux in the 9.6 and 15 μ m bands	ergs/(cm ² sec)
FXWAV	Net flux in the H ₂ O bands	ergs/(cm ² sec)
FX15C	Net flux in the 9.6 and 15 μ m bands	ergs/(cm ² sec)
FAC	Conversion factor for cooling rate	
COOLR	Cooling rate	°C/day

2. Subroutine INDATA

Code	Meaning	Unit
PUI	See main program	ergs/(cm ² sec) K ⁻¹
GFH2O	G-function	
TRE	CO ₂ transmission function	
FSN	Coefficients for correcting CO ₂ transmittance	
TAUW	Transmittance in the 15μm band due to H ₂ O line absorption	
TAUU	Transmittance in the 15μm band due to H ₂ O e-type absorption	
TOZON	Ozone transmission function	
TWIN	Transmittance in the 9.6μm band due to e-type absorption	
NP	Number of flux levels	
NPT	Total number of sublevels	
NSB	Number of sublayers between neighboring flux levels	
NT	Number of temperature values in GFH2O	
NW	Number of log w values in GFH2O	
NUP1	Number of u values in GHF2O	

3. Subroutine GAMOTO

Code	Meaning	Unit
PA	See main program	
TA	See main program	
WA	See main program	
PUI	See main program	
PAI	Pressure at the middle of sublayers	mb
DPI	Air mass in a sublayer	gm/cm ²
TUI	Temperature at sublevels	K
TAI	Temperature at the middle of sublayers	K
RAWI	Specific humidity in a sublayer (01800)	gm/gm
RAWI	Water vapor content in a sublayer (01840)	gm/cm ²
TS, TSS	Surface temperature	K
WBAR	Scaled water vapor amount for line absorption	gm/cm ²
UBAR	Scaled water vapor amount for e-type absorption	gm/cm ²
PRE	Reference pressure	mb
RR	Coefficients for computing R	
CS, CSS	Fractional cloud cover	
NXT	Index for cloud top pressure	
NXB	Index for cloud base pressure	
CLTOP	See main program	
CLBOT	See main program	
NC	See main program	

4. Subroutine IRH2O

Code	Meaning	Unit
TEMP1	Initial temperature value for array GFH2O	K
SW	Initial value of log w for array GFH2O	
DT	Increment in temperature values in GFH2O	K
DW	Increment in log w in GFH2O	
DU	Increment in u in GFH2O	gm/cm ²
IH	Temperature index for GFH2O	
KW	Index of log w for GFH2O	
KU	Index of u for GFH2O	
DH	Difference between the sublevel temperature and the temperature at the nearest index value.	K
FW	Difference between the value of log w and that at the nearest index value.	
FU	Difference between the value of u and that at the nearest index value.	gm/cm ²
SH	Planck flux at sublevels	ergs/(cm ² sec)
FLUXUS	Upward flux at the surface	ergs/(cm ² sec)
SHT	$G(p, p_t, T_t)$	ergs/(cm ² sec)
SHS	$G(p, p_s, T_s) - G(p, p_s, T(p_s))$	ergs/(cm ² sec)
SG	$(\partial G/\partial T) \Delta T$	ergs/(cm ² sec)
GFH2O	See subroutine INDATA	
DELTA	Correction term for Planck fluxes	ergs/(cm ² sec)
DGDT	$\partial G/\partial T$	ergs/(cm ² sec K)
TDEL	$(\partial G/\partial T) \Delta T$	ergs/(cm ² sec)
WDEL	$(\partial G/\partial \log w) \Delta \log w, (\partial G/\partial u) \Delta u$	ergs/(cm ² sec)
NUP1	See subroutine INDATA	
NP	See subroutine INDATA	

4. Subroutine IRH2O (Continued)

Code	Meaning	Unit
NPT	See subroutine INDATA	
NSB	See subroutine INDATA	
NW	See subroutine INDATA	
NT	See subroutine INDATA	
TS	See main program	
TUI	See subroutine GAMOTO	
WBAR	See subroutine GAMOTO	
UBAR	See subroutine GAMOTO	

5. Subroutine FDIVER

Code	Meaning	Unit
FLUX	Σ SG	ergs/(cm ² sec)
FLUXU	Upward flux in the water vapor bands	ergs/(cm ² sec)
FLUXD	Downward flux in the water vapor bands	ergs/(cm ² sec)
SUMC	Total cloud cover	
NP	See subroutine INDATA	
NPT	See subroutine INDATA	
NSB	See subroutine INDATA	
NC	See main program	
CS	See subroutine GAMOTO	
NXT	See subroutine GAMOTO	
NXB	See subroutine GAMOTO	
SG	See subroutine GAMOTO	
SH	See subroutine GAMOTO	
SHS	See subroutine GAMOTO	
SHT	See subroutine GAMOTO	
FLUXUS	See subroutine GAMOTO	

6. Subroutine RCO2O3

Code	Meaning	Unit
TEMP1	Initial temperature value for arrays BLKCO2 and BLKWIN	K
SW	Initial value of log w for TAUW	
SU	Initial value of log u for TAUU and TWIN	
DT	Increment in temperature values in BLKCO2 and BLKWIN	K
DW	Increment in log w in TAUW	
DU	Increment in log u in TAUU and TWIN	
NT	Number of temperature values in BLKCO2 and BLKWIN	
NK	Number of log w values in TAUW	
LINEXP	Flag for correcting CO ₂ transmittance due to temperature variations	
RLAT	Latitude	degree
LAT	Index for latitude	
TAI	See subroutine GAMOTO	
TR	U.S. Standard Temperature profile	K
DTAI	Temperature deviation from TR	K
WBAR	See subroutine GAMOTO	
UBAR	See subroutine GAMOTO	
BLKCO2	Precomputed Planck flux in the 15 μ m band	ergs/(cm ² sec)
BLKWIN	Precomputed Planck flux in the 9.6 μ m band	ergs/(cm ² sec)
BAI	Planck flux in the middle of sublayers in the 15 μ m band	ergs/(cm ² sec)
BWI	Planck flux in the middle of sublayers in the 9.6 μ m band	ergs/(cm ² sec)
BS	Upward flux at the surface in the 15 μ m band	ergs/(cm ² sec)
BSS	Upward flux at the surface in the 9.6 μ m band	ergs/(cm ² sec)
FSN	See subroutine INDATA	
TOZON	See subroutine INDATA	

6. Subroutine RCO2O3 (Continued)

Code	Meaning	Unit
TRE	See subroutine INDATA	
TAUW	See subroutine INDATA	
TAUU	See subroutine INDATA	
TWIN	See subroutine INDATA	
TAUF	Transmittance in the 15 μ m band	
TXUF	Transmittance in the 9.6 μ m band	
FLUXC	$\Sigma B \Delta \tau$ in the 15 μ m band	ergs/(cm ² sec)
FLUXW	$\Sigma B \Delta \tau$ in the 9.6 μ m band	ergs/(cm ² sec)
FLUXDC	Downward flux in the 15 μ m band	ergs/(cm ² sec)
FLUXUC	Upward flux in the 15 μ m band	ergs/(cm ² sec)
FLUXDW	Downward flux in the 9.6 μ m band	ergs/(cm ² sec)
FLUXUW	Upward flux in the 9.6 μ m band	ergs/(cm ² sec)
FLUXU	Total upward flux in the 9.6 and 15 μ m bands	ergs/(cm ² sec)
FLUXD	Total downward flux in the 9.6 and 15 μ m bands	ergs/(cm ² sec)
NC	See main program	
NXT	See subroutine GAMOTO	
NXB	See subroutine GAMOTO	
CS	See subroutine GAMOTO	
SUMC	Total cloud cover	
NP	See subroutine INDATA	
NPT	See subroutine INDATA	
NSB	See subroutine INDATA	

APPENDIX C

SAMPLE OUTPUT

1. Clear Mid-Latitude Winter Atmosphere (NC = 0)

NDATA	NC	RLAT	TS	PS
40	0	15.0	270.0	1013.0

PRESSURE LEVELS(MB) OF SAMPLE PROFILE

0.2	0.3	0.5	0.7	1.0
2.0	3.0	4.0	5.0	6.0
7.0	8.5	10.0	12.5	15.0
17.5	20.0	25.0	30.0	35.0
40.0	50.0	60.0	70.0	85.0
100.0	125.0	150.0	175.0	200.0
250.0	300.0	350.0	400.0	500.0
600.0	700.0	850.0	920.0	1000.0

TEMPERATURES(K) AT THE ABOVE PRESSURE LEVELS

240.64	252.60	258.73	264.03	263.21
255.07	243.47	236.23	230.82	226.98
224.70	222.30	219.89	217.36	216.80
216.33	215.93	215.42	215.20	215.20
215.20	215.20	215.20	215.31	215.87
216.43	217.05	217.69	218.23	218.69
219.27	222.39	229.03	234.55	242.40
251.24	258.73	264.69	268.32	270.57

HUMIDITY(GM/GM) AT THE ABOVE PRESSURE LEVELS

0.285E-05	0.439E-05	0.548E-05	0.663E-05	0.820E-05
0.111E-04	0.118E-04	0.127E-04	0.135E-04	0.143E-04
0.155E-04	0.169E-04	0.185E-04	0.202E-04	0.193E-04
0.186E-04	0.180E-04	0.173E-04	0.138E-04	0.105E-04
0.853E-05	0.700E-05	0.512E-05	0.468E-05	0.415E-05
0.400E-05	0.400E-05	0.453E-05	0.745E-05	0.195E-04
0.195E-04	0.244E-04	0.500E-04	0.100E-03	0.272E-03
0.574E-03	0.102E-02	0.166E-02	0.210E-02	0.242E-02

CLOUD TOP CLOUD BOTTOM CLOUD FRACTION

210.	300.	0.18
210.	300.	0.18

PRESSURE FLUXES IN H2O BANDS FLUXES IN 9.6 & 15 MICRON BANDS

PRESSURE (Mb)	DOWN (ERGS/CM**2/SEC)	UP (ERGS/CM**2/SEC)	DOWN (ERGS/CM**2/SEC)	UP (ERGS/CM**2/SEC)
1.39	0.0	185444.37	0.0	46202.96
3.18	267.87	185390.31	2061.45	47522.17
7.28	287.19	185349.50	2958.25	46955.96
16.67	632.25	185324.37	4343.21	47013.10
38.16	1855.69	185351.94	6837.71	48156.27
87.36	2985.56	185424.69	10492.16	50072.78
200.00	6850.19	185616.37	14897.36	51975.02
300.00	14780.50	187467.50	17737.02	54861.20
400.00	28260.62	190267.00	23370.52	59365.65
500.00	47726.87	194613.50	29131.07	63406.77
600.00	69482.19	201169.56	35583.37	67895.44
700.00	92101.81	208026.37	42254.19	71718.94
800.00	110372.37	213865.00	47685.18	74349.87
900.00	128080.00	219744.00	52466.74	77183.87
1013.00	147111.94	223162.00	57425.71	78223.00

PRESSURE COOLING RATE

FROM (MBAR)	TO (MBAR)	COOLING RATE (DEGREE CELCIUS/DAY)
1.39	3.18	14.55
3.18	7.28	3.09
7.28	16.67	1.71
16.67	38.16	0.92
38.16	87.36	0.48
87.36	200.00	0.46
200.00	300.00	0.51
300.00	400.00	1.00
400.00	500.00	1.42
500.00	600.00	1.44
600.00	700.00	1.58
700.00	800.00	1.29
800.00	900.00	1.16
900.00	1013.00	1.46

ORIGINAL PAGE IS
OF POOR QUALITY

2. Cloudy Mid-Latitude Winter Atmosphere (NC = 5)

NDATA NC RLAT TS PS
40 5 15.0 270.0 1013.0

PRESSURE LEVELS(MB) OF SAMPLE PROFILE

0.2	0.3	0.5	0.7	1.0
2.0	3.0	4.0	5.0	6.0
7.0	8.5	10.0	12.5	15.0
17.5	20.0	25.0	30.0	35.0
40.0	50.0	60.0	70.0	85.0
100.0	125.0	150.0	175.0	200.0
250.0	300.0	350.0	400.0	500.0
600.0	700.0	850.0	920.0	1000.0

TEMPERATURES(K) AT THE ABOVE PRESSURE LEVELS

240.64	252.60	258.73	264.03	263.21
255.07	243.47	236.23	230.82	226.98
224.70	222.30	219.89	217.36	216.80
216.33	215.93	215.42	215.20	215.20
215.20	215.20	215.20	215.31	215.87
216.43	217.05	217.69	218.33	218.69
219.27	222.39	224.03	234.55	242.40
251.24	258.73	264.69	268.32	270.57

HUMIDITY(G./GM) AT THE ABOVE PRESSURE LEVELS

0.285E-05	0.439E-05	0.548E-05	0.663E-05	0.820E-05
0.111E-04	0.118E-04	0.127E-04	0.135E-04	0.143E-04
0.155E-04	0.169E-04	0.185E-04	0.202E-04	0.193E-04
0.186E-04	0.180E-04	0.173E-04	0.138E-04	0.105E-04
0.653E-05	0.700E-05	0.512E-05	0.468E-05	0.415E-05
0.400E-05	0.400E-05	0.453E-05	0.745E-05	0.195E-04
0.195E-04	0.244E-04	0.500E-04	0.100E-03	0.272E-03
0.574E-03	0.102E-02	0.166E-02	0.210E-02	0.242E-02

CLOUD TOP CLOUD BOTTOM CLOUD FRACTION

210.	300.	0.18
505.	600.	0.06
801.	901.	0.15
600.	900.	0.06
204.	902.	0.04

PRESSURE (MB)	FLUXES IN H2O BANDS (ERGS/CM**2/SEC)		FLUXES IN 9. 6 & 15 MICRON BANDS (ERGS/CM**2/SEC)	
	DOWN	UP	DOWN	UP
1.39	0.0	160269.50	0.0	43336.52
3.18	267.87	160215.44	2081.45	42645.90
7.28	287.19	160174.56	2958.25	42049.80
16.67	832.25	160148.75	4343.21	41992.21
38.16	1855.69	160173.62	6037.71	42797.15
87.36	2985.56	160240.19	10492.16	44245.09
200.00	6050.19	160410.25	14657.36	45780.01
300.00	34820.18	177958.44	20919.61	52523.17
400.00	46781.64	181566.06	26296.43	57142.21
500.00	63775.48	186278.69	31799.63	61207.65
600.00	89371.12	196293.62	39297.41	66551.94
700.00	115026.87	204333.69	46916.28	70682.81
800.00	130624.25	210515.56	51979.39	73420.44
900.00	159386.06	219744.00	59768.91	77283.87
1013.00	173253.37	223182.00	63878.33	78223.00

PRESSURE (MBAR)		COOLING RATE (DEGREE CELCIUS/DAY)
FROM	TO	
1.39	3.18	14.59
3.18	7.28	3.16
7.28	16.67	1.81
16.67	38.16	1.06
38.16	87.36	0.56
87.36	200.00	0.49
200.00	300.00	0.82
300.00	400.00	0.77
400.00	500.00	1.16
500.00	600.00	1.50
600.00	700.00	1.78
700.00	800.00	0.99
800.00	900.00	1.98
900.00	1013.00	1.02

3. Clear Tropical Atmosphere (NC = 0)

NDATA NC RLA1 TS PS
40 0 15.0 297.8 1013.1

PRESSURE LEVELS(MB) OF SAMPLE PROFILE

0.2	0.3	0.5	0.7	1.0
2.0	3.0	4.0	5.0	6.0
7.0	8.5	10.0	12.5	15.0
17.5	20.0	25.0	30.0	35.0
40.0	50.0	60.0	70.0	85.0
100.0	125.0	150.0	175.0	200.0
250.0	300.0	350.0	400.0	500.0
600.0	700.0	850.0	920.0	1000.0

TEMPERATURES(K) AT THE ABOVE PRESSURE LEVELS

229.36	246.72	255.63	263.31	269.91
265.47	257.36	251.76	247.68	244.41
241.76	239.03	236.29	233.26	230.23
227.77	225.66	222.96	220.12	217.96
216.11	212.61	207.66	203.59	199.42
195.30	197.54	205.47	211.85	218.32
226.22	235.13	243.39	249.66	259.20
269.24	278.52	286.72	292.90	297.17

HUMIDITY(GM/GM) AT THE ABOVE PRESSURE LEVELS

0.200E-05	0.314E-05	0.395E-05	0.482E-05	0.570E-05
0.870E-05	0.990E-05	0.107E-04	0.117E-04	0.124E-04
0.134E-04	0.149E-04	0.166E-04	0.187E-04	0.191E-04
0.184E-04	0.178E-04	0.171E-04	0.147E-04	0.109E-04
0.871E-05	0.692E-05	0.498E-05	0.435E-05	0.368E-05
0.336E-05	0.327E-05	0.349E-05	0.437E-05	0.755E-05
0.255E-04	0.919E-04	0.239E-03	0.458E-03	0.936E-03
0.196E-02	0.319E-02	0.794E-02	0.116E-01	0.141E-01

CLOUD TOP CLOUD BOTTOM CLOUD FRACTION
200. 300. 0.45

PRESSURE (MB)	FLUXES IN H2O BANDS (ERGS/CM**2/SEC)		FLUXES IN 9.6 & 15 MICRON BANDS (ERGS/CM**2/SEC)	
	DOWN	UP	DOWN	UP
1.39	0.0	236907.69	0.0	62255.73
3.18	300.94	236876.50	2649.86	61631.22
7.28	307.37	236827.25	4193.17	60845.29
16.67	953.00	236673.75	6140.75	60214.68
38.16	2034.50	236570.31	8110.90	60700.78
87.36	2685.94	236504.87	8774.48	62061.51
200.00	5388.50	237562.12	12586.56	69809.12
300.00	20093.37	240090.44	20464.41	76473.31
400.00	51892.06	246632.06	29464.14	82664.81
500.00	81082.94	255275.69	37862.09	88353.25
600.00	113158.37	266878.50	46950.80	94578.75
700.00	146335.19	282323.06	56815.86	100479.94
800.00	179883.44	294606.62	65878.81	105042.31
900.00	219928.56	312925.06	76076.56	111535.56
1013.10	269846.69	329867.37	91195.87	115737.44

PRESSURE (MBAR)	COOLING RATE (DEGREE CELSIUS/DAY)	
	FROM	TO
1.39	3.18	17.04
3.18	7.28	4.90
7.28	16.67	3.04
16.67	38.16	1.03
38.16	87.36	0.01
87.36	200.00	-0.17
200.00	300.00	1.13
300.00	400.00	2.37
400.00	500.00	1.96
500.00	600.00	1.97
600.00	700.00	1.83
700.00	800.00	2.18
800.00	900.00	2.15
900.00	1013.10	3.28

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16. Abstract <p>This report is the documentation of a FORTRAN program that calculates the atmospheric cooling rate and infrared fluxes for partly cloudy atmospheres based upon the fast but accurate methods of Chou and Arking (1978, 1980). The IR fluxes in the water bands and the 9.6 and 15 μm bands are calculated at 15 levels ranging from 1.39mb to the surface.</p> <p>The program is generalized to accept any arbitrary atmospheric temperature and humidity profiles and clouds as input and return the cooling rate and fluxes as output. Sample calculations for various atmospheric profiles and cloud situations are demonstrated in the report.</p> <p>A digital magnetic tape containing the computer codes and the precomputed transmission functions of the radiation routine can be made available upon request.</p>			
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